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OIL FUEL

S. H. North

OIL FUEL.

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OIL FUEL:

ITS SUPPLY, COMPOSITION, AND APPLICATION.

BY

SYDNEY H. NORTH,

LATE EDITOR OF THE "PETROLEUM REVIEW."

With a Folding Plate and 41 Illustrations.

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PREFACE.

THE object which the author of this book has had before him has been that of providing, as concisely as possible, a record of the developments and progress made in the application of oil fuel to power purposes. The gradual evolution of the burner to its present state of efficiency; the various problems connected with the combustion of oil fuel in a furnace; the advantages, economic and mechanical, which accompany the use of oil fuel for different purposes,—these subjects have all been dealt with in the light of the latest experience. The book will, therefore, it is hoped, prove a valuable one for those who desire to become acquainted with the general progress and conditions of the use of oil fuel, and also for those who have occasion to refer to different points in various branches of the subject.

S. H. N.

January 1905.

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OIL FUEL.

CHAPTER I.

THE SOURCES OF SUPPLY.

One of the most important factors in connection with the use of liquid fuel is the supply available for the various purposes to which it is now being put. As time goes on this element will not play so important and controlling a part; but the United Kingdom having no oil deposits of its own, except the shale oil of Scotland, which is, of course, unsuitable for fuel purposes, the supply must always exercise a more than usually important influence on the matter of its employment. Until quite recently the chief source from which oil suitable for fuel could be obtained was Russia, while it has also been obtained in smaller quantities from other countries. Russian oil has, however, continued the main supply, and the bulk of this has been consumed in the country itself, chiefly on the steamers on the Caspian Sea, on the Trans-Caucasian Railway, and in certain industrial establishments. The oils obtained from the Baku fields are highly suitable for the production of that quality of residual which is adaptable to fuel purposes. During the last three or four years, however, several other large deposits of heavy oil have been discovered in different parts of the world, which supplement, to a very important extent, the previous stores. These discoveries have been made in the island of Borneo, and in Texas and California. It is a somewhat remarkable fact that all the most recent discoveries of oil deposits have been those of the heavy-oil description, providing a proportionately small amount of the higher-class products, but yielding good supplies of lubricating oil and oil suitable for fuel purposes. This remark applies equally to Borneo, Texas, and California. In fact, since the discovery and development of the great Pennsylvanian fields no oil has been found of such a high grade, that is, capable of yielding so large a percentage of illuminating oil, and these fields are fast becoming exhausted.

It is, of course, a very difficult matter to estimate the stores of oil available in the various fields; in fact, it may be said to be impossible, for, unlike coal and other solid minerals, it can readily shift about and leave one region for another. Almost the only indication of the supply that one can obtain is the condition of the wells and the superficial area of the land which is believed to be oil-bearing. Naturally, this is a very rough and ready, not to say misleading, method of arriving at a decision as to the quantities available, and although attempts have been made to give figures representing the latter, it is quite impossible to rely on them. If the estimates of the quantities of coal stored in the United Kingdom can only be accepted as slightly approximate, much more so must those referring to oil be held in doubt. The usual method of arriving at a figure in connection with oil supply is to take the area designated as oil-bearing, the number of wells it is possible to put down, and the average output that each well may be expected to yield. Anyone with the slightest acquaintance with the oil industry will recognise what a very unreliable method this is. It is certain, to begin with, that the whole area is not similarly productive, and that one well may produce and another may not, also that certain spots away from the anticlinal will not be productive at all. Therefore, when statements are made to the effect that there are such and such quantities obtainable from a certain area, we can only wonder at the intrepidity of the man who made the calculation, and at the credulity of those who accept such figures. It is impossible, in this case, to estimate the quantity of oil that is available for liquid-fuel purposes, and to say that the supply will last over a certain number of years. Recent events in Texas have, at least, emphasised this fact, that unless another and more prolific supply of fuel oil is discovered in the near future, the application of liquid fuel will be considerably hampered, if not very seriously checked. Without indulging in anything like a prophecy, but rather drawing inferences from analogy, it appears likely that the next discovery of oil will be of such a character as will be most suitable for fuel purposes. The occurrence of heavy oils will be dealt with in a separate chapter, and the subject, therefore, need not be referred to in more detail here.

We may pause for a moment to consider the present condition of the existing sources of supply. Russia is undoubtedly the most extensive and the most reliable. There is nothing doubtful or uncertain about the vast Baku deposits; the only drawback is their geographical position, which, however, might be greatly improved by providing more numerous and reliable facilities for the transport of the oil to the seaboard of the Black Sea. The Russian Government, as well as the Russian producers themselves, have been singularly lacking in enterprise and foresight in not perfecting the means of transport for the oil to other European countries. A pipe-line, if not a canal, in conjunction with a canalised river, should years ago have been provided for the conveyance of oil from Baku to the Black Sea. However, probably in less than two years' time the Baku-Batoum pipe-line will be in use, and this should have a very favourable effect on the oil trade of Russia, and on the liquid-fuel trade all over the world.

At the present time the production of fuel oil in Russia amounts to nearly 40 million barrels (1902), the quantity being larger for 1903. Of the former figure, the largest proportion was consumed in the country itself, the bulk, of course, on the Trans-Caucasian Railway. The quantity exported is but a small proportion of the quantity produced, the remainder being retained for the Caspian Sea vessels and for industrial purposes. Thus it will be seen that Russia does not help the liquid-fuel trade in foreign countries to any great extent.

The next supply to enter into competition was that of the island of Borneo, which was obtained from fields owned and developed by the Shell Transport and Trading Co. The oil raised here is also of a heavy description, and is therefore suitable for fuel purposes, a large quantity having been brought into this country and disposed of chiefly to railway companies. The extent of the supply in these fields is as unknown as that in Russia and Texas, although of recent years the shipments of liquid fuel, solar oil, etc., have practically been suspended. This, however, may be a matter of policy, as the Shell liners have been well occupied in conveying Russian oil to the East and Texan oil to Europe. Sir Marcus Samuel, the chairman and managing director of the company, has stated convincingly that they possess an oil-field in Borneo capable of supplying the whole world with fuel oil. The Borneo fields have been tested over an extent of sixty miles; wells have been put down sixty miles apart at points running longitudinally, and the same description of oil in large quantities has been found. The fields are capable of providing several million tons of liquid fuel a year. The Borneo fuel is very limpid—as limpid as water. It contains no pitch whatever, and it is impossible that it can clog the tubes of the burner. The difficulty has been that it is so viscid that the noise which is produced by steam is detrimental to its use, because it sprays so rapidly that it disperses much more quickly than it ought to do, and does not go into complete combustion under steam. That difficulty is obviated by the use of air. The specific gravity is high, that obtained from a depth of 700 feet being 0·970, while that at a depth of 1400 feet has a specific gravity of 0·896. The oil yields about 25·30 per cent. of illuminating oil, the remainder being fuel oil.

The Texas fields are of a very different nature from those of Russia and Borneo, in that the wells put down have turned out to be nearly all gushers of a very high producing power in the first instance. Certainly, the field has much more the aspect of being a temporary producer, or an isolated pool, than any of its contemporaries. In Borneo the wells have been much more moderate in their manner of yielding the oil, while in Russia, although most prolific spouters have been common, these have been spread over a wider area, and have not had the appearance of being fed from the same source. This is an important feature in the case, because it affects the exhaustibility of the supply one way or the other. When the Texas wells began to yield, the output amounted to as much as 10,000 barrels a day per well, some even exceeding this figure; after a few months, however, the gas-pressure greatly diminished, and the daily output was, of course, substantially reduced, and three and a half years after the bringing in of the field the yield of the wells was not more than 100 barrels per well per day, the oil having to be raised by means of pumping. This output is, of course, a good one for the American fields, and is certain to show a great falling off in a year or so, if not before. The main drawback to the Texas field is that its area is very small, and the wells outside the limit already described are nothing like so productive as those situated at its centre, namely, Spindle Top. Of the total quantity of oil raised, so far, from this Beaumont field, but a small proportion has been brought into the United Kingdom. The bulk of the oil produced is consumed in America itself, and, therefore, the price does not stand much chance of experiencing a very large reduction. America has ample scope and possibilities of consuming pretty well all that these new fields can yield, and there is far more likelihood of its threatening the position of coal in certain districts in that country than of its doing so as an imported commodity in this. Other fields, however, are being opened up in the same State which may supplement the deposits of the Beaumont field.

As regards the Californian oil and its relation to the liquid-fuel question, this can at present only be considered as a purely local advantage. The oil is admirably suited for fuel purposes, and there is a plentiful and increasing supply, although the nature of its occurrence is different from that in the Texas fields. Spouters are few, and much less volcanic than those in the latter state, but the field is more stable and settled, and there therefore seems a greater dependence on the supply. At the present time the whole of the oil available is consumed in California itself, chiefly on the Santa Fé and Southern Pacific Railways, and also extensively in various industrial establishments in and around San Francisco. Thus the Californian supply does not come into outside markets, and does not affect the liquid-fuel question in a general sense. When the production is so augmented that a balance is left available, the countries which will enjoy the benefit thereof will either be the more eastern and southern American States, or the countries situated in the Orient.

There are, of course, also large deposits in Canada which, according to local opinion, are highly suitable for use as fuel. The production in the oil-fields of Western Ontario amounts to about 30,000,000 gallons of crude petroleum annually. The oil is of a heavier specific gravity than that of the United States, and contains a larger percentage of carbon than either the Russian or American oil, and is therefore specially adapted for use as fuel. Oil has been successfully used as fuel there for the last thirty years under ordinary steam boilers, as well as under the stills, where a much higher temperature is required. If this Canadian petroleum is obtainable in sufficient quantities, and could be delivered at a reasonable figure, it would be extremely convenient for England to draw the supply of liquid fuel for her warships from British territory.

Burmah also possesses large and prolific fields, and the crude oil is suitable for providing a good supply of liquid fuel, although up to the present the consumption has been confined to local use.

Among the new districts in Texas where another large supply of heavy oil has been brought to light, though it is apparently not to be compared with the Beaumont field for productivity, is that of Sour Lake. The oil obtained here has a specific gravity of ·963, and yields over 70 per cent. of residuals of a specific gravity of ·978. The extent of the field has not yet been ascertained, and opinions differ considerably as to its value. A good number of wells have been put down and are fairly productive, but there is not the subterranean energy apparent that is so marked a feature at Spindle Top. Oil obtained here at a depth of 250 feet had the specific gravity already given; at 450 feet it was ·915; at 640 feet, ·909; and at depths below this it remained practically unchanged. Professor Thiele, who has made an exhaustive examination of the field, believes that it has a very productive future before it.

A deposit of heavy oil is also being worked in Algeria, which region has been so ably brought before the oil world by M. Henri Neuburger, of Paris. The crude oil yields 42 per cent. suitable for burning and 10–12 per cent. of paraffin scale, the remainder being residuals. Experiments have proved that the Dahra oil is very suitable for fuel purposes.

Every day efforts are being made to extend the existing limits of the oil-bearing areas in all parts of the world, and every year some new addition is made to the sources of supply. It is no great show of optimism, nor beyond the bounds of reason and experience, to believe that within the next year or two, perhaps earlier, another deposit will have been tapped and another field opened up which will place the liquid-fuel question above the control of price and geographical position.

CHAPTER II.

THE ECONOMIC ASPECT OF LIQUID FUEL.

THE advocates of liquid fuel, as compared with solid fuel, have up to the present found themselves in a somewhat anomalous position. They have had to maintain the great economic advantages of petroleum for fuel in the face of a prohibitive price. The two points are entirely distinct, but in this age of money values a commodity has to be cheap to be regarded as offering economic advantages. The compensations, however, offered by liquid fuel are so many that a high price can be allowed, provided, of course, that, when all the former are taken into consideration, there is no excess of actual money cost against it. Coal is, under any conditions, a dirty, wasteful, and variable means of raising steam and providing power. Its quality varies so enormously that its wastefulness is not always appreciated to its full extent. There are a number of constituents which are not at all necessary to the provision of heat; they are injurious to boilers and furnaces, and harmful to individuals working with them. Coal is difficult to mine, costly to handle, and entails a lot of unnecessary work in use. The labour of removing the refuse from burnt coal is almost as great as feeding the fire itself. The vast difference between liquid fuel and coal is no more graphically seen than in the bunkering of a vessel with coal, and loading her up with oil. It is typical of the two descriptions of fuel—the one the embodiment of ease and efficiency, the other of clumsiness and uncleanliness. Coal has maintained its position as chief power-provider for so long because the greatest steam-using countries have vast stores of the mineral, and because national expediency and welfare come above every other consideration in industrial life. Then, too, the appliances which are used for heating and power purposes have all been fitted for the use of the solid fuel, and to discard old and familiar customs is not an easy process in any country. Even America has not been able to thrust on one side in a day the methods instituted at the beginning of its industrial existence. With such a vital thing as fuel—the basis of all trade, industry, and commerce—this change must necessarily be slow, though it need not be conservative. It must not be forgotten, however, that, whatever drawbacks coal possesses as a fuel, the large deposits still available in the foremost industrial countries of the world are not at all likely to be neglected on account of the advantages of liquid fuel: not one mine will be shut down because liquid fuel has displaced the solid product, and not a single miner is likely to be deprived of his living on this account. Petroleum is the great supplementary fuel supply for coal, just as electricity has supplemented coal gas for lighting, and steam for power purposes. Yet there has been no falling off in the use of coal for either of these purposes; rather has it increased the consumption by giving an impetus to the two branches of industry.

In regard to the use of coal for raising steam, it does not seem possible that engineers have reached the end of their resources in improving the means by which the heating power of coal is utilised. The full efficiency of coal has never yet been obtained, nor anything like it, and if methods and appliances were introduced, greatly increasing this heating efficiency, it would undoubtedly give coal a longer life. This argument is also applicable to liquid fuel, the use of which has not yet been thoroughly mastered. The burners are not as efficient as they will, no doubt, become, and the conditions under which the fuel should be burnt are not yet thoroughly understood, and are, therefore, not as economical as they might be. The fuel itself is a much more delicate thing to handle than coal; it is more sensitive to external conditions, and, therefore, requires a considerable amount of scientific investigation to enable the ordinary man to be put in possession of facts and principles necessary to get the best and surest work out of it.

Nevertheless, even at the present stage of the use of the fuel, petroleum has certain distinct economic advantages over coal. As has already been mentioned, the method of obtaining the fuel is much simpler and less costly than that of coal; the preliminary treatment of the oil before use in some cases amounts to nothing more than exposure in the open air for a certain period; in others, such as the Russian, the residuals are obtained after the kerosene has been distilled off. When obtained, the ease and cheapness with which it can be shipped and transported are in very favourable comparison with the methods necessary for the bunkering of coal, and how much cleaner is the former than the latter!

In its application still more significant economies come to light, especially on steamships, mercantile and naval. In the locomotive, the scope for economy is far more limited and less noticeable, chief among the advantages being the ease and cleanliness of loading up with fuel, and the greater heat and speed obtainable from the liquid commodity. Then liquid fuel affords a greater facility in responding to increased loads, which is, of course, an important item in connection with railway traffic, where the loads are so variable. The loading up is a point which is equally apparent in locomotives as in steamships, though the quantities are not so large in the former case. Mr James Holden, of the Great Eastern Railway, states that a main-line express engine can take in 600 gallons of liquid fuel in from four to five minutes—a wonderful saving in time compared with coal.

On steamships the extent of the economy is greatly emphasised, as the requirements are on a much more extended scale. Even the most superficial of these advantages on board ship shows oil fuel in a favourable light. In bunkering with coal, everything on the vessel is made grimy with the dust rising from the solid fuel, and this necessitates considerable labour in cleaning up again. What a different picture does a vessel using oil fuel present! The ship is as clean as before loading up; little or no labour is required in the process, as the oil can either be run from the storage tanks on shore by means of gravity, or it can be pumped in from barges or the tank steamer. The fuel, if in liquid form, may also be stored away in the ballast tanks, the oil as it is drawn off being replaced by water. In a merchant ship this means more space available for cargo, and in a warship it means greater fighting room, more boiler space, and, seeing that a greater amount of power is stored in oil, weight for weight, than coal, a much wider range is given to the vessel. Sir Fortescue Flannery, M.P., in his paper before the Institution of Naval Architects, placed this range of action as being increased by 50 per cent. on the bunker weight allotted and 90 per cent. upon the bunker space allotted when oil is the fuel used. Thirty-six cubic feet of oil are equivalent to 67 cubic feet of coal, and in the matter of weight two tons of oil are equal to three tons of coal. These are undoubted economic advantages, and are of vital importance to a battleship.

Another economic advantage of oil fuel in both merchant and warships is the small number of men necessary to attend to the furnaces. The question of stoking on ships has always been a difficult one, but liquid fuel reduces the difficulties to a minimum. In certain cases the stokehold staff has been reduced from thirty-two to eight when using oil, and not only is this economy effected, but, to quote Sir Fortescue Flannery again, the difficulty in maintaining the full-power speed, as compared with the performance when the ships were new, due to the trimming and stoking not being done to the fullest capacity of the boilers, is overcome. This is a benefit which must strongly appeal to all shipowners. Uniformity of steaming is synonymous with economy and augmented profits.

For naval purposes the smokelessness of liquid fuel is also one of its favourable features, and with proper combustion this is always obtained. Considering also that the chemical composition of coal and petroleum fuels, dealt with in another chapter, is practically identical, the smokelessness of the latter proves it to be more capable of perfect combustion than coal, and therefore far more economical; for as everyone knows, in spite of the decades that have passed since steam power came into use, no appliance or method introduced has ever yet been efficient enough to procure anything approaching perfect combustion, that is, the full heat-efficiency of the solid fuel.

The question of rebunkering at sea is another matter which has greatly exercised the naval authorities. The difficulties with a solid fuel in this direction must always necessarily be numerous, but with a liquid fuel these drawbacks disappear. So easily can the supply be transferred from one vessel to another, that a simple length of tubing will do the work of fifty men, and three hundred tons be shipped in one short hour. The value of this facility is so apparent in the case of a warship requiring to be rebunkered away from port that it needs no emphasis, while the saving in time, labour, and fuel is equally apparent.

Other economies there are also in the substitution of liquid for solid fuel. Although there is some difference of opinion in regard to the wear of the boiler plates, etc., the general consensus of opinion is that liquid fuel is much less injurious to the boilers and furnaces than coal. In the majority of cases it has been found that petroleum has damaged the iron and steel work to a very small degree, a result which is due to the more equable distribution of temperature throughout the heating surfaces, and to the entire absence of ashes in the furnace.

In the matter of actual fuel economy, the experience which has been gained on the Shell liners may be stated briefly here. These vessels have burned liquid fuel for a longer period continuously than any other ships with reference to which data are obtainable. The consumption of oil on S.S. *Clam* over a period of two years, during which time she traversed 89,000 miles, amounted to 18 tons per day. For the first six years of her life, coal was the fuel employed, and the consumption amounted to 26–28 tons per day. The *Murex*, another Shell tanker, consumed 25 tons of coal per day, but after being converted to an oil-burner her consumption amounted to only 16 tons of oil. The *Strombus*, one of the largest Shell liners, burned 43 tons of coal and, subsequently, 30 tons of oil per diem.

In a paper read by Mr E. L. Orde, of Messrs Armstrong, Whitworth & Co., before the N.E. Coast Institute of Engineers and Shipbuilders, it was stated that the best results of evaporative efficiency obtained show 12·5 lbs. of water from and at 212° per lb. of oil; with Borneo oil this gives a fuel efficiency of 64·6 per cent. With the best types of burners this is increased to 13–14 lbs. This, however, appears somewhat lower than has been obtained in other quarters; 16 lbs. of water per lb. of oil has been attained, against 9 with coal, showing an increase by oil equal to 77 per cent. This evaporation, of course, greatly depends on the conditions of burner and furnace, and on the manner in which the burners have been manipulated.

CHAPTER III.

CHEMICAL COMPOSITION OF FUEL OILS.

THE composition of petroleum is a matter of such complexity that a lifelong study would not suffice for acquiring a thorough knowledge of its chemical possibilities. In connection with its use as liquid fuel, however, it is not necessary to go deeply into detail, nor in a treatise of this description is it imperative to give much more than general information on the subject. The oil chiefly used for fuel purposes is that known under the name of "residuals," or, in Russia, "astatki" or "mazout," the latter being the Tartar word for the residue left over from the crude oil after refining. In some cases the crude oil as it is obtained from the earth is also suitable for fuel purposes, provided it has been permitted to stand in the open air for a short period, in order to allow the lighter oils to pass away, and thus remove the dangerous ingredients. Borneo and Texas crude oils are in their natural state suitable for fuel—the latter, according to some authorities, not until after the removal of the sulphur contents. The crude products of Russia and California have to undergo a certain course of distillation, from which a residue is obtained forming one of the best oils for fuel purposes extant. The composition of the fuel oils of the world is as under; their calorific values are also appended:—

	Carbon.	Hydrogen.	Oxygen, etc.	Calorific Values. B.T.U.
Russia . . .	84·94	13·96	1·25	18,611
Borneo . . .	87·8	10·78	1·24	18,831
Texas . . .	85·66	11·03	3·31	19,242
Burmah . . .	86·4	12·1	1·5	18,864

Of Baku petroleum, or rather the residue after distillation, M. Bertin, chief constructor of the French Navy, says it is an ideal fuel for marine boilers. This petroleum, when subjected to distillation, gives off, firstly, light naphtha, then kerosene to the extent of about 30–35 per cent. After this a residue of heavy oil, called "mazout" or "astatki," is left in the still, which is chiefly used as fuel. A certain proportion is used also for the production of lubricating oils. These residuals do not give off any vapour below 248° F., neither will they flash under 302° F. Moreover, they may be exposed without danger to the explosion of a Hotchkiss shell, says M. Bertin. Their storage and handling, therefore, present little risk. The chief components of Russian residuals are from 11 to 13 per cent. of hydrogen, from 84 to 87 per cent. of carbon, and from 1 to 1·75 per cent. of oxygen.

In reference to the Texas oils, data presented by Messrs C. Richardson and E. E. Wallace to the Society of Chemical Industry (New York Section) may be given here. The following tables show the composition of the Beaumont oil compared with other American oils, and also the results of the distillation tests of the same:—

ULTIMATE COMPOSITION.

	Beaumont.	Penna.*	Ohio.†
C	85·03	86·10	85·00
H	12·30	13·90	13·80
S	1·75	0·06	0·60
O and N	0·92	...	0·60
Loss on treatment with excess of H_2SO_4 .	39·0	21·0	30·00

* Engler.

† Mabery, Noble Co.

Distillation Tests (*Engler's Flasks*).

	Beaumont. Test No. 44,651.	Ohio. Test No. 19,708.	Pennsylvania. Test No. 46,483.
Distillation begins	110° C.	85° C.	80° C.
Below 150° C. . . . per cent.	2·5	23·0	21·0
150°–300° C. . . ,,	40·0	21·0	41·0
300°–350° C. . . ,,	20·0	21·0	14·0
350°–400° C. . . ,,	25·0	27·0	2·03, 99·0
Loss on acid treatment (150°–300° C. fraction)	10·0	5·0	1·8
150°–260° C. . . per cent.	30·0	...	...
Loss on acid treatment . ,,	8·0	...	...
Percentage of acid used . ,,	7·0	2·5	2·0

It will be observed from the figures representing the chemical composition of the oils that the Beaumont oil contains a high percentage of sulphur compared with other oils, and this constituent has caused a great deal of controversy in regard to its injuriousness from a fuel point of view. It is certain that the proportion is larger than in most descriptions of coal used for power purposes, but its removal is easily and cheaply effected, and does not appear to have given much trouble in practice.

The Borneo oils, which are of an ideal consistency for fuel purposes, are no doubt destined to play a very important part in the liquid-fuel question, especially in the Far East. Data in reference to these oils are not very easily obtainable, and the figures appended showing the analyses of them are taken from articles contributed by M. Ragosine, the well-known Russian chemist, to a periodical of that country, and of which translations appeared in English in the *Petroleum Review*.

In the Balek Pappan field, a light crude oil of about 0·870 and a heavy one of about 0·970 are obtained.

A sample of the light crude oil analysed by M. Ragosine gave the following results:—

Specific gravity at 15° C.	0·896

FRACTIONAL DISTILLATION.

No. of Fraction.	Boiling Point. ° C.	Per Cent.	Specific Gravity.	Quantity of Products.
Kerosene 1st .	130–150	0·9	...	...
2nd .	150–170	3·0	0·783	1. Loss . . . 1·5 p.c.
3rd .	170–190	10·5	0·794	2. Kerosene distillate . . 44·0 ,,
4th .	190–210	6·0	0·811	3. Solar distillate . 8·0 ,,
5th .	210–230	6·4	0·831	4. Residuals . . 46·0 ,,
6th .	230–250	9·0	0·850	
7th .	250–270	9·0	0·874	100·0 p.c.
8th .	270–290	8·5	0·892	
Residuals .	...	46·7	0·975	

In the Sanga-Sanga field, there are also a heavy and a light crude oil.

The heavy crude oil has a specific gravity of 0·980, and contains only a certain quantity of solar oil (about 15 per cent.) and 85 per cent. of residuals.

The light crude oil, which M. Ragosine analysed, showed the following composition:—

Specific gravity of the crude oil at 15° C. . . 0·862

FRACTIONAL DISTILLATION.

No. of Fraction.	Boiling Point. ° C.	Per Cent.	Specific Gravity.	Quantity of Products.
Benzine . .	110–130	11·2	0·763	1. Benzine and loss 18·5 p.c.
Kerosene 1st .	130–150	11·3	0·783	2. Kerosene distillate . . 51·9 ,,
2nd .	150–170	10·5	0·799	3. Residuals . . 29·6 ,,
3rd .	170–190	7·3	0·811	
4th .	190–210	8·0	0·828	
5th .	210–230	6·5	0·850	
6th .	230–250	7·5	0·876	
7th .	250–270	7·7	0·905	
8th .	270–290	3·6	...	
Residuals .	...	26·0	0·971	

The residuals in both cases are liquid.

If the two descriptions of oils from Balek Pappan and Sanga-Sanga are treated together in equal proportions, then the relative quantity of products obtained at the refinery are:—Benzine and loss, 9 per cent.; kerosene, 26 per cent.; solar oil, 7 per cent.; residuals, 58 per cent.

Several samples of liquid fuel taken by M. Ragosine at Singapore gave the following tests:—

	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity at 15° C.	0·962	0·968	0·965	0·961
Flash point (by Martins Pensky apparatus)	107° C.	104° C.	68° C.	84° C.
Viscosity (by Engler-Ragosine)	2·9	3·2	2·3	2·3
Water	present	present	present	absent

The very great difference in flash point was due to the fact that the refinery produces two classes of liquid fuel: the first, with a flash point above 100° C., to supply places where the high flash point is required by the laws of the country (for instance, in British India and Japan); and the second, with a lower flash point, being adapted to countries where there are as yet no flash point regulations.

The latest field which yields an oil suitable for fuel is that of Sour Lake, in Texas, situated some miles to the north of the Beaumont wells. The analysis of the oil has been made by Professor Thiele, and is as under:—

ANALYSIS OF CRUDE OIL, STRATA 272 FEET BELOW SURFACE.

Fraction.	Temp. °C.	P.c. by Vol.	Sp. Gr.	Colour.
1.	...	trace	...	White.
2.	212–266	0·07	...	Yellow.
3.	266–320	0·03	...	Yellow.
4.	320–392	1·59	0·684	Yellow.
5.	392–572	19·49	0·840	Bl. Fluor.
6.	...	...	...	Bl. Fluor.
7.	572–641	5·15	0·782	Dark Yellow.
Residue	...	71·11	0·978	Black.
	Total	97·44		

The oil contained 20 per cent. asphaltum.

Specific gravity of crude oil, 0·963 at 63° F., water being 1·0.

The oil was impregnated with sulphuretted hydrogen, and compounds rich in nitrogen.

According to the foregoing analysis, the crude oil could be divided into the following commercial products:—

	Per Cent.
Benzine	0·07
Heavy illuminating oil	16·24
Middle oil	27·79
Fraction to be worked into lubricating oil and asphaltum .	53·34
Total	97·44
Loss in refining	2·56
Total	100·00

So far, five different oil-yielding strata have been found at Sour Lake. The densities of the different oils are as follows:—

	Specific Gravity.
Oil at 250 feet depth	0·963
,, 450 ,, ...	0·915
,, 640 ,, ...	0·909
,, lower depths	0·909

In concluding this chapter on the chemical composition of the various fuel oils, it may be interesting to introduce a table showing the composition, calorific value, and evaporative power of different descriptions of British coal.

Coal (from several Samples).	Specific Gravity.	C.	H.	O.	S.	Ash.	Moisture.	B.T.U.	Lbs. of Water.
Welsh . .	1·315	83·8	4·8	1·0	1·4	4·1	4·9	14,470	14·98
Newcastle . .	1·256	82·1	5·3	1·3	1·2	5·7	3·8	14,432	14·94
Derby and Yorks	1·292	79·7	4·9	1·4	1·0	10·3	2·6	13,582	14·06
Lancashire .	1·273	77·9	5·3	1·3	1·4	9·5	4·6	13,552	14·03
Scotch . .	1·260	78·5	5·6	1·0	1·1	9·7	4·0	13,804	14·29
Average British .	1·279	80·4	5·2	1·2	1·25	7·87	4·0	13,968	14·46

CHAPTER IV.

CONDITIONS OF COMBUSTION IN OIL-FUEL FURNACES.

THE opportunities of observing the process of combustion, as well as other phenomena, characteristic of the burning of oil as fuel are few and inadequate, though the matter is of considerable moment to engineers. Some observations have, however, been made by Mr Edwin L. Orde, of Messrs Armstrong, Whitworth & Co., while Professor Vivian B. Lewes has dealt with the subject from a purely chemical point of view. With the idea that these experiences will be of value, and may lead to further investigations and results, the remarks of these gentlemen are reproduced here. The former conveyed his observations through a paper to the Institution of Mechanical Engineers, and the latter in a lecture at the Petroleum Institute. Both contributions reflect the position in which liquid-fuel practice finds itself at the present time, and define the difficulties which still remain to be overcome.

"When coal is burnt in a furnace," says Professor Lewes, "a large proportion of the heat transmitted to the water takes place by radiation, and it is clear that in our method of burning oil it will have to be determined whether it is better to so arrange the air supply as to produce almost non-luminous flames, such as those given by the atmospheric burner, or whether the air supply should at first be limited, so as to give a highly luminous flame, and the air needed to complete the combustion only added when the combustion chamber is reached. A non-luminous flame gives but little radiant heat, whilst the incandescent particles in a luminous flame give a very considerable amount. My own impression is that to facilitate the transmission of a portion of the heat as radiant heat the flame in the furnace itself should be luminous, and that the combustion should be completed by the addition of more air at the entrance to the combustion chamber before the tubes are reached.

"The transmission of heat from a non-luminous flame in the furnace to the water in the boiler is but small, as the contact of the surface of the furnace crown extinguishes the flame, and leaves a layer of badly conducting gases between the metal and the flame. It is for this reason that, when the mass of radiating fuel on the furnace grate is done away with, and is replaced by the flame of burning hydrocarbons, it becomes necessary to use fire-brick or other refractory material in the furnace, in order that it may become highly heated, and by its radiation aid the transmission of heat to the water in the boiler.

"There is another side, however, to the question which must not be overlooked, and that is, that it is necessary to dilute the oil gas as far as possible before combustion, in order to prevent the deposition of carbon, which, once formed, is very difficult to reburn, and is one of the chief causes of smoking. If the effect of the steam is merely the mechanical one of injecting, and afterwards diluting, the oil gas, and no chemical action took place, the advantage would be entirely on the side of such injectors as do their work by pressure and not by steam, but it must be remembered that, as the oil spray is heated in the furnace space in presence of the steam, chemical action takes place and greatly simplifies the composition of the hydrocarbons.

"It may be roughly taken that the petroleum residue chiefly employed will approximate to $C_{12}H_{26}$, that is to say, will be a mixture of hydrocarbons, the composition of which is around this point, and if this be brought in contact with sufficient steam in the hot furnace space, the action, if complete, would result in the formation of carbon monoxide and hydrogen—

$$C_{12}H_{26} + 12H_2O = 12CO + 25H_2;$$

whilst under ordinary working conditions, the proportion of steam being far less than this, the result would be hydrocarbons of a more simple molecular structure diluted by hydrogen and carbon monoxide, such a mixture being comparatively easy to burn without formation of smoke, whilst the rich oil gas and oil tar vapours formed by the heating when no steam is there to aid the chemical interactions are excessively difficult to burn without the formation of smoke.

"Some observers have tried to argue that the utilisation of steam for direct pulverisation of the oil adds enormously to the heating effect by producing in this way hydrogen and carbon monoxide, but this, of course, is an utter mistake, as it takes just as much heat to break up the steam as is evolved by the after combustion of the products formed, that is to say, the balance of heat will remain unchanged, whether the oil be burnt alone with air, or whether it be decomposed by steam and the products then burnt, the great advantage of the steam being to facilitate the combustion of the oil without the formation of smoke, which undoubtedly must give increased heat by preventing the escape of unconsumed products.

"One of the questions which is of the greatest possible importance in the combustion of liquid fuel is the regulation of the air supply in such a way as to complete the combustion within the area possible to allow in the boiler. This requires most careful experimental research in order to determine not only the volume, but also the particular stage in the combustion at which it answers best to add it.

"In the combustion of liquid fuel the oil is practically entirely converted into gas, vapour, and floating particles of finely divided carbon before combustion begins, or at any rate before any large amount has been consumed. This requires a large combustion area, as the volume of air needed to complete the action and prevent smoking is very great, whilst with coal the combustion of the largest proportion of the fuel takes place on the furnace grate, and it is only the escaping gases distilled out of the coal and formed by the incomplete combustion that have to be burnt in the crown of the furnace and combustion chamber.

"The question of combustion area and air supply needed for the use of liquid fuel is made clear when one considers, in figures, the work which has to be done. With a service vessel under full steam, if the best Welsh coal is used, there will be little or no smoke, showing that combustion has been fairly complete, whilst one knows that if one took a Newcastle or Durham coal there would be abundant black smoke from the funnel, showing that already the combustion area and air supply were insufficient to deal with the work that had to be performed. If one took the actions taking place with a bituminous coal as representing the maximum efficiency of combustion that could be obtained by that particular arrangement of boiler and furnace, one would be certainly overstating and not understating the efficiency.

"The action of the heat from the fire in the grate when the coal is first charged in very closely resembles the actions that take place in the gas-maker's retort, as the red-hot fuel below is raising the fresh fuel above to a temperature of about 1000 degrees C., and is preventing any large amount of air from getting through the bed of incandescent carbonaceous material to it. Under these conditions a ton of bituminous coal would yield 10,000 cubic feet of gas and ten gallons of tar in the condition of vapour, whilst 75 per cent. of the weight of the coal would be left to burn on the fire grate, a certain proportion of which, by incomplete combustion, would yield carbon monoxide to add to the body of gas to be burnt up in the crown of the furnace and the combustion chamber.

"On the other hand, when a ton of astatki is converted into gas, on being injected into the furnace, it yields double this quantity, *i.e.*, 20,000 cubic feet of gas and about 12 per cent. only of residual tar in the form of vapour and carbon particles. Not only is the volume of gas thus yielded twice as great in the case of oil fuel as in the case of coal fuel, but it is a gas which, being far richer in hydrocarbons, requires a far greater volume of air for its complete combustion than was the case with the gas developed from the coal, so that it can easily be understood that a furnace with its combustion area and air draught arranged for coal, cannot be expected to deal with nearly the same weight of liquid fuel.

"It must be borne in mind that the area over which the combustion spreads is governed by the length of travel of the combustible gases before they find the necessary amount of atmospheric oxygen for their complete combustion, and that the conditions of air supply mean, to a great extent, regulation of combustion space; but whilst doing this and completing the combustion of large volumes of oil in a small space, a limiting factor will soon be found in the intensity of the temperature attained, so that the important factor to be determined is the weight of oil that can be consumed per cubic foot of combustion space, without throwing an undue strain from overheating on the material of boiler and fittings."

The experiments carried out by Mr E. L. Orde were made with crude Borneo oil, the composition of which is: carbon, 87·9 per cent.; hydrogen, 10·78 per cent.; and oxygen, 1·24 per cent. The flash point is 211° F., and the boiling point 395° F. The calorific value, determined by the Bomb calorimeter, is 18,831 B.T.U.

All fuel oils are exceedingly complex, being made up of a number of combinations of carbon and hydrogen which only a chemist who has devoted himself to investigating hydrocarbons can appreciate at their true significance. The importance of this point for the practical purposes of the engineer lies in the fact that the various constituents of the fuel give off vapour at temperatures varying from about 100° F. up to the boiling point of the oil, and when the boiling point is approached—unless special precautions are taken—a residue of solid carbon is formed which will soon choke any pipes or narrow passages through which the fuel may have to pass.

An important characteristic of these hydrocarbon compounds is that in the presence of superheated steam they can be completely distilled without cracking, and the explanation of this fact has been stated to be that in the presence of superheated steam the boiling point, or, more correctly, the mean boiling point, of the oil is lowered. This distillation, however, does not apparently take place with any other medium but steam.

To ensure distillation it is necessary that the temperature of the oil should be raised to as near the boiling point as possible before it is admitted into the presence of the steam, and it is in this part of the process that the danger of cracking appears. In the apparatus fitted by Messrs Armstrong, Whitworth & Co., the difficulty has been overcome, and, so far as it has been possible to ascertain by ordinary means, complete vaporisation has been secured. The vapour thus produced can be completely oxidised by the amount of air chemically necessary, and a larger quantity of oil can, therefore, be treated in the same furnace space than by either of the two other systems, while the combustion, as shown by the analyses of waste gases, is complete.

	I. Per Cent.	II. Per Cent.
Carbon dioxide	13·2	12·6
Oxygen	3·6	4·0
Carbon monoxide	...	...
Hydrocarbon gases	...	...
Hydrogen	...	...
Nitrogen	83·2	83·4

The only feature calling for remark is the somewhat large percentage of uncombined oxygen, which is no doubt due to leakage around the smoke-box. As regards efficiency, an evaporation of from 15 to 16 lbs. from and at 212° should always be obtained with dry Borneo oil.

The hydrocarbon vapour is exceedingly unstable, and appears to depend for its existence entirely on temperature. The exact form in which the combustion of these hydrocarbon vapours takes place does not seem to be clearly understood. The appearance of the flame at a distance of a few inches from the nozzle of the burner suggests that at that point the hydrocarbons are burning in the form of acetylene, which all gaseous hydrocarbons do at a temperature of 1000° F. As the flame proceeds further into the furnace, however, and the temperature becomes higher, the hydrocarbon combination must break up, and the rest of the vapour is probably burned as carbon monoxide and hydrogen.

"It has been suggested by some of the early writers on the subject," says Mr Orde, in another contribution, "that liquid fuel has a higher calorific value than solid fuel of the same chemical composition, from the fact that a certain amount of heat has been rendered latent in passing it from the solid to the liquid form; and it has therefore been argued that heat values calculated on the basis of solid carbon are underestimated to the extent of this latent heat of liquefaction. Dr Paul, who investigated the subject very closely, has suggested 6000 B.T.U. as the value of the heat thus lost, but as this is the value assigned by Rankine to the latent heat of the gasification of solid carbon, it would appear to be too high for the latent heat of its liquefaction. The determination of the heat value of petroleum by the Bomb calorimeter does not show the existence of this latent heat, and Dr Paul comes to the conclusion that it is not probable that petroleum, when used as fuel, can be made to evaporate more than about 16 lbs. of water from and at 212° F. This agrees with nearly all the well-authenticated results that are on record.

"Taking Borneo oil as an example, a heat balance sheet that has been experimentally obtained is given below.

HEAT BALANCE SHEET OF BORNEO OIL.

Loss due to Moisture.	Units of Evaporation.			
1. $\frac{10{\cdot}78}{100} \times 9 \times (212 - t) + 966 + 0{\cdot}48(T - 212)$ (where t = *initial temperature of oil.* T = *temperature of escaping gases.*)	1·15	1·0	1·2	1·19
2. Losses due to heat carried off in escaping gases. $\frac{1 + A^1 \times T}{4000}$. ($A$ = *weight of air required for combustion* (*observed*))	1·46	1·6	2·3	2·21
3. Loss due to radiation (observed) . .	1·3	1·4	1·3	1·38
4. Heat employed in evaporation . .	15·4	15·4	14·5	14·6
Total heat value of oil . .	19·4	19·4	19·4	19·4

"The heat lost in radiation was measured at a separate trial; the amounts thus found were interpolated in the balance sheet, and found to agree very closely with the result found by difference in the usual way, in all cases but the second, when the observed evaporation was undoubtedly too high. The observed evaporation results were 15·4, 15·95, 14·6, and 14·48 respectively. The difference between the first and second pairs of experiments is due to the presence of water in the oil. This exercises a very important function on the behaviour of the fuel, and is responsible for much of the difficulty that has attended its use. The actual reduction of the heat value of the fuel =13·14 B.T.U. per 1 per cent. water, in addition to the loss of the oil which it replaces; for example, 1 lb. of oil mixed with 10 per cent. water evolves

18,831 × 0·9 = 16,947·9 B.T.U.
less 131·4 ,,
= 16,816·5 ,,

a difference of 1915·5 B.T.U., or a loss in evaporative power of nearly 2 lbs. of water from and at 212°.

"Besides this actual loss of heat, the presence of water destroys the conditions necessary for perfect combustion, and this occurs and may cause considerable damage to boilers of the ordinary marine type, although the quantity is not sufficient to extinguish the flame. The first effect is naturally to reduce the temperature of the flames and thereby increase their length, thus moving the point of highest temperature further into the furnace, which has the effect:—

1st. Of rendering a large portion of the furnace heating surface entirely useless;
2nd. Of raising the temperature in the combustion chambers to a point which may be hurtful to the material; and
3rd. Of causing the last stage of combustion to take place in the smoke-box and funnel.

"The conditions that attend and the reactions that take place in burning liquid fuel in boiler furnaces present a problem which has apparently not received the attention which it deserves. Petroleum vapour depends entirely on temperature, and it is therefore almost impossible to collect samples when actually burning it in a furnace. It seems obvious that the first effect of the furnace heat on the petroleum spray is to liberate hydrocarbon vapours, and to ignite them on the outer surface of the jet. The ignition raises the temperature of the whole of the jet, and probably dissociates some at least of the hydrocarbon vapours into carbon monoxide and hydrogen. In what form the undissociated hydrocarbon vapours burn it is difficult to conjecture, but the appearance of the flames suggests that acetylene is present. This might conceivably arise from the reaction $CH_4 + CO = H_2O + C_2H_2$. As the temperature of the flame rises, the hydrocarbons are probably all dissociated, and burn as CO and H to CO_2 and H_2O without further change. When the conditions are satisfactory, the flames are opaque and dazzling white in colour for a distance of some six inches from the nozzle of the burner, become semi-transparent and almost violet in colour at the middle of their length, and shade into red at the end. In burning oil which is mixed with water the combustion is incomplete, the violet colour never appears, and the end of the flame is dark red and fringed with smoke. In some cases, where water is present in comparatively small quantities, the end of the flame is white and presents the appearance of acetylene, which may arise from want of sufficient heat in the flame to decompose the hydrocarbons. This has been observed when, although no smoke was formed and the air supply was not more than 20 per cent. above what is chemically necessary for the fuel, the evaporative performance of the boiler was poor, which confirms the existence of a low furnace temperature."

CHAPTER V.

EARLY METHODS AND EXPERIMENTS.

ALTHOUGH there is no intention of making this book an historical record in any lengthy manner, it will be desirable, as well as of value, to give a general survey of the early methods and appliances which have been used, and of the experiments which have been carried out for improving the appliances for adapting oil to fuel purposes.

As far back as 1861 a mechanic named Werner, engaged in a refinery in Russia, first suggested that the refuse oil might be burnt as fuel. He adopted various contrivances, but ultimately settled on an apparatus consisting of a series of grates or griddles, over which the liquid trickled and burnt. A patent was taken out by him for this device in 1867, and many firms used it, but gave it up when improved appliances were available.

In 1862 attention was directed in America towards the application of petroleum for heating and power. Another early method of burning the oil was by means of a pan or step over which the oil flowed and was ignited, while almost at the same time Shaw and Linton patented in America a furnace in which the fuel was conveyed into the interior in a gaseous state, the oil being previously heated and made to give off its lighter oils, which were subsequently consumed inside the furnace. Undoubtedly, this was a more advanced idea than that of burning the oil in its natural state openly in the bottom of the hearth, and reference will be made to this principle later. In the year following (1863) the first spray furnace was introduced into America by a Mr Brydges Adams for use on locomotives; yet, in spite of this great improvement and the more perfect combustion of the fuel obtained, a year later Richardson introduced into England what was known as an oozing furnace. In this furnace, which was experimented with by the inventor in conjunction with the Admiralty, the bottom is lined with ordinary burned slack lime, spread evenly at the top, but with a number of small vaultings at the bottom of the layer. The oil enters these spaces from tanks, and penetrating the lime, which acts as a sort of wick, becomes ignited and is consumed. Later experiments were made with this method of burning the oil, with the result that a commission appointed by the Admiralty reported very favourably thereon, though the system was not adopted, owing to the prohibitive price of liquid fuel. The experiments, however, served to show that unmixed oils had a greater evaporative power than mixed, the latter in this case consisting of tar oil and shale oil, and, in one instance, tar, shale, and American crude oils.

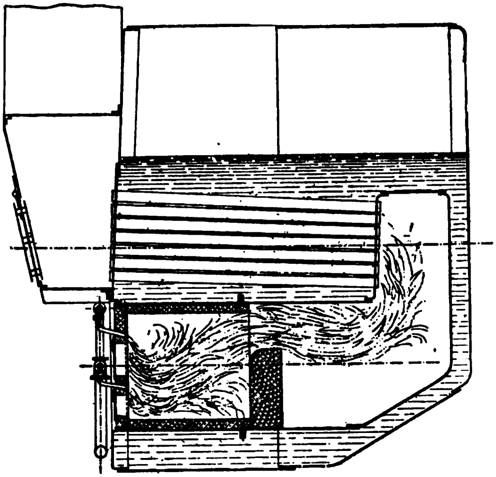


FIG. 1.—Audouin's furnace.

The next year (1865), another drop furnace (fig. 1) was invented by Audouin in France, and in the year following Messrs Aydon, Wise, and Field of London took a great step forward by introducing their nozzle-sprinkler, which marked an era in the use of liquid fuel, and of which further details will be given. In 1867 came another gas furnace (fig. 2), invented by Foote in America, which was experimented with by the U.S. Navy Department on board a gunboat; but although the results of the tests were said to be excellent, little more was heard of the method, which, from a description, appears to have been somewhat complicated. Another of these gas furnaces was introduced into England in 1868, and was tried on a steamship, the *Retriever*, of 500 tons. The working of this system seems to have given satisfactory results, and a short description of it will be presented.

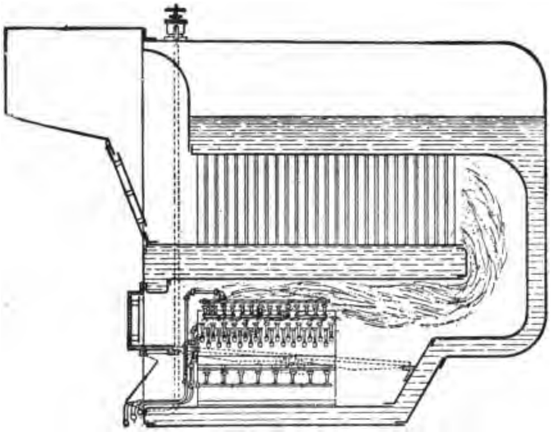


Fig. 2.—Foote's gas furnace.

In this same year St Claire-Deville introduced a new drop furnace in France, something on the same principle as that of Audouin, which was used under the boilers of the steam yacht *Puebla*. In this instance a heavy tar oil of a specific gravity of 1·044 was used, and her engines showed an increase of 2 horse-power over coal, while the consumption of oil amounted to 3·94 lbs. of oil per horse-power per hour. This same system was employed on the locomotives of the Chemin de Fer de l'Est, where 22 lbs. of oil evaporated 24 lbs. of water, compared with 22 lbs. of coal briquette evaporating 17·6 lbs. of water.

The year 1868 also marks another epoch in the progress of liquid fuel, for in it Admiral Selwyn made his now historic experiments with a burner which he himself devised with Aydon, one of the joint inventors of the burner invented two years previously by Aydon, Wise, and Field. These experiments are noteworthy in that they were carried out with the sanction and under the direction of the Admiralty. The burner was a nozzle-sprinkler, and was undoubtedly the most efficient introduced up to that time. Before describing this among others, this brief review may be concluded.

By this time the primitive form of liquid-fuel furnaces had practically gone out of use, although as late as 1878 an oozing furnace was introduced by Paterson in New Jersey. The spray and jet had come to be recognised as the only efficient forms of burners, although these had many variations and were applied in different ways. In 1870 came the Lenz burner, which was used extensively on the Caspian Sea and the Volga. An improvement was made in this later, which provided a circular opening for the oil instead of a flat one, and the tongue was also altered in such a manner that a broader flame was obtained. In 1872 Körting invented a burner which also underwent considerable modifications four years later, and in 1874 Professor Urquhart introduced a burner for adoption on the Russian railways, but this early form was soon dropped on account of the large consumption of oil involved, and about the year 1883 a new type was introduced, which was fitted to a very large number of Russian locomotives. In the year 1880 the Brandt burner (fig. 3) was introduced, and good results were obtained, though its chief disadvantage was that, when cleaning was necessary, steam had to be shut off, which was an expensive and often inconvenient task.

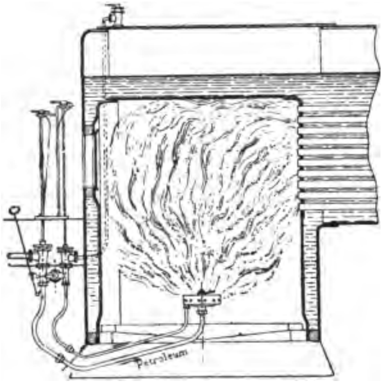


FIG. 3.—Brandt's burner.

The burner of Aydon, Wise, and Field is one of the earliest methods of burning petroleum as fuel, and was first used at South Lambeth in 1866 with a Cornish boiler. The oil entered from a vertical pipe through an opening about 1·2 inches in diameter, through which it flowed from a tank above at the rate of about 3·3 gallons per hour. During its course the oil was forced into the discharge pipe by the stream of superheated steam escaping from the horizontal pipe, which drew in air through the funnel. The oil, steam, and air met and mixed in this pipe, and arrived through a cone-shaped mouth over the fire-door into the fire-box. About 3 feet 3 inches from the fire-door was a bridge of tiles against which the stream of oil and steam impinged in the form of a cloud of thin vapour, the superheated steam having distributed part of the oil and vaporised the remainder. The unconsumed particles of this vapour either became ignited at a coal fire or against the fire-bridge, which was intensely hot. This ignition was facilitated by the previous mixture with air. The supply of oil was regulated by a tap in the supply pipe, the steam by a spindle, and the air by a cap. The fire was lighted by placing some red-hot coals on a sheet of iron on the grate, which afterwards ignited the oil.

The burner of Aydon and Selwyn (figs. 4 and 5) was used in the trials conducted by the Admiralty at Greenwich in 1868 with a Field marine boiler. Aydon modified his apparatus so that the oil and steam met at an acute angle.

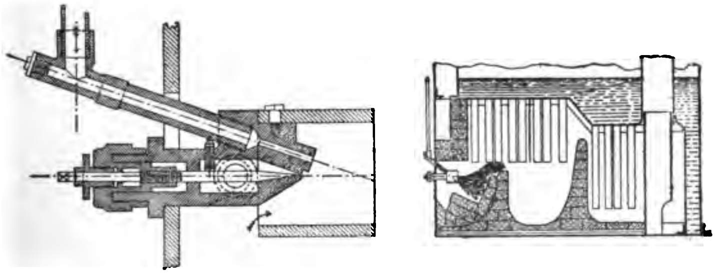


Fig. 4.—Aydon and Selwyn's burner ; and, 5, arrangement of furnace.

The steam spray was regulated by a tapering spindle, which was kept in position by a small pressure screw. The pipe in which the meeting of oil, steam, and air took place remained the same, except that an opening was provided beneath for the admission of air. During the first experiments of Selwyn two fire-bridges were placed in the fire-box and the floor was covered with fire-bricks. Subsequently this brickwork was removed, and the fire-bridge alone remained. A coil of piping was, however, hung between the Field tubes, and through this the steam, being previously superheated, had to pass before it arrived at the sprinkler. The fire-door was removed, and was replaced by a cross-barred slide, by means of which the air was regulated. The results of the trials made showed a 7·5-fold evaporation with coal, against a 10·5-fold evaporation with tar residual. The Admiralty was so satisfied with this, that the boiler of H.M.S. *Oberon* was placed at Admiral Selwyn's disposal for further experiments. This had a heating surface of 1707 feet, whereas the Field boiler had a heating surface of only 1063 square feet. For these experiments Admiral Selwyn used a nozzle-sprinkler in which the oil was delivered through a central pipe, and the steam through a concentric pipe. With a view to making the boiler immediately available for coal firing, the grate was not removed, but was merely covered with fireproof stones, which attained a white heat, and were found excellent non-conductors. For the same reason the steam superheating pipe had to be placed to the forward smoke-box. During a three hours' trial, on November 13, 1868, 2·2 lbs. of tar oil evaporated 33·9 lbs. of water at a temperature of 100½° F. with a steam pressure of 40¼ lbs. The other trials did not show results quite so satisfactory. In cases of water of a temperature of 212° F. the best result attained was an evaporation of 37¼ lbs. of water with 2·2 lbs. of tar oil, the theoretical evaporating power of which is put down at 38·6 lbs. A perfect combustion of the oil was therefore practically obtained.

In the burner of Dorsett and Blythe (fig. 6) the retort and burners were separate. Experiments with this appliance were carried out on board the *Retriever*. When steam was generated the two boilers employed were filled with heavy tar oil of 1·050 specific gravity, and this was evaporated by means of an ordinary coal fire. When the oil vapour reached a pressure of about 20 lbs. per square inch it was conveyed to the retorts of the furnaces, where it entered a couple of burners, which continued the evaporation of the oils. When the oil vapour had attained a pressure of 50 lbs. per square inch, or a temperature of 932° F., it was admitted to the furnaces. About 75 mm. above this a sheet of iron was attached, which extended backwards as far as the combustion chamber. About 75 mm. still higher another iron sheet was placed, shorter and perforated. This was covered with fire-bricks. The back opening between the two sheets was filled up with these bricks, the forward part only partly, so that a certain volume of air could enter and find its way through into the furnace. Another volume of air, regulated by means of a sliding valve, entered into the combustion chamber between the lower iron sheet and the ash-plate. The gas-supply pipe entering each furnace ran along the fire-bricks as far as the combustion chamber, and then turned back. The combustion chamber at the back, common to all three furnaces, also contained a gas pipe which communicated with those in the furnaces. The gas pipes in the furnaces had four holes of 0·08 inch in diameter, and that in the combustion chamber had eight such holes, so that the boiler was heated by twenty gas flames. Each pipe had an entrance and a vent tap, the first for regulating the supply, and the latter for carrying off any condensed oil which might form during the heating. In consequence of the very high temperature of the oil vapour, the retort boilers as well as the gas pipes were covered with a coating of sheet iron,

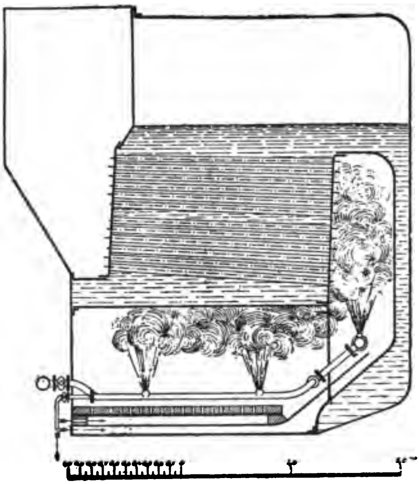
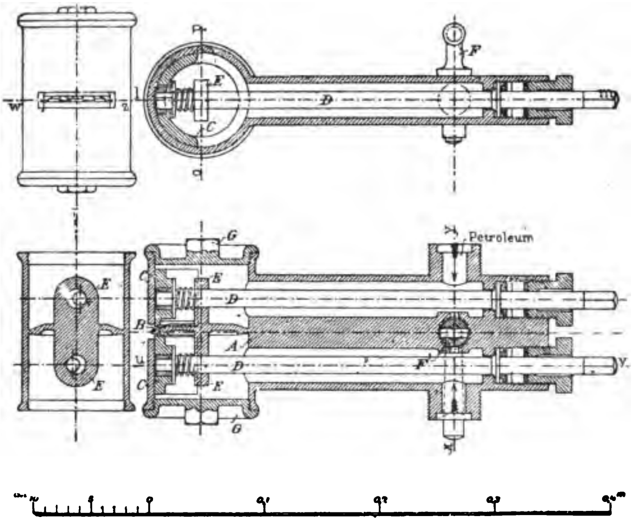


FIG. 6.—Dorsett and Blythe's gas furnace.

and the spaces between were filled up with sand and pottery. About 150 horse-power was given out by the engine, which means, at an hourly consumption of 529 lbs. of oil, about 3·52 lbs. of oil per indicated horse-power per hour. The evaporation, which was 12·35-fold, according to Paul, agrees with these data. The combustion also seems to have been good, and very little smoke was given out by the steamer.

Lenz's first sprinkler (figs. 7 and 8) was introduced in 1870,



Figs. 7 and 8.—Lenz's first burner.

and was extensively used on the steamers of the Caspian Sea and lower Volga. In this burner two pipes lead to the sprinkler in the fire-door; the upper one conveys the oil, and the lower one the steam. The sprayer is divided into two by a partition A (fig. 8), thus preventing the intermixture of oil and steam. This division terminates in a tapering tongue B, in the grooves of which the oil flows out to be blown into separate thin sprays by the steam that comes out from underneath this tongue. The intervals between the sprays of oil serve to facilitate the access of air. The flow of oil and steam is regulated by the circular slides C C, which are pressed by spiral springs against the inner walls of the cylindrical sprinkler. A spigot fastened eccentrically in the axle of the spindle D grasps each slide. The spindles D are firmly packed at E against the partition, and terminate outside the sprinkler with a square section, so that they can be turned by keys, and thus effect the displacement of the slides. Should the flow of the oil be stopped, the oil pipe is shut off, the tap F is opened, and the tongue openings are then blown through. When a thorough cleaning is necessary, the cover G is unscrewed. The first Lenz sprinklers were not at all satisfactory, as the flame did not uniformly heat the furnace, and combustion was imperfect, while the walls and ends of the pipes were destroyed. Soot formed in considerable quantities, and a very poor duty was obtained per indicated horse-power per hour, requiring as much as 6·6 to 7·7 lbs. of mineral oils.

The new slit-sprinkler of Lenz was furnished with a circular opening round the cylindrical chamber, instead of a straight slit. This insured a circular flow of the oil spray. The slides were also made cylindrical, and were movable backwards and forwards in the chamber. For this purpose grooved eccentric rings were placed round the spindles, and run along a groove in the centre of the slides. The tongue was also altered for the purpose of obtaining a broader flame. This improvement was specially adapted for marine boilers and locomotives, and through its introduction the utility of the Lenz sprinkler was greatly augmented, although its cost was considerably increased.

The nozzle-sprayer of Körting (figs. 9 and 10) was introduced in 1876, and has been used in boilers arranged for coal fires without requiring any change in the fire-box. The non-superheated steam is admitted into the sprinkler by the valve A, and enters first into a well-shaped compartment, from which it escapes into the nozzle through small orifices in the copper tube. This arrangement ensures the liberation of the steam from the deposited water, the volume of which might become very considerable in a small steam pipe only 15 mm. in diameter. The condensed water does not pass out of the orifices with the steam, but remains behind in the bell-shaped compartment, and is drawn off from time to time by means of the screw valve C. The steam streaming through the nozzle sucks in the air through the orifices E, mixes with it, and this mixture vaporises in the mouthpiece F an oil spray 6 mm. diameter, which flows out of the nozzle and is regulated by a tap. The vapour spray and the oil spray meet at an angle of 90 deg., and, as will be noticed, the flame is blown slantingly into the fire. The air sucked up by the steam jet is said to produce a better combustion by being drawn through oil.

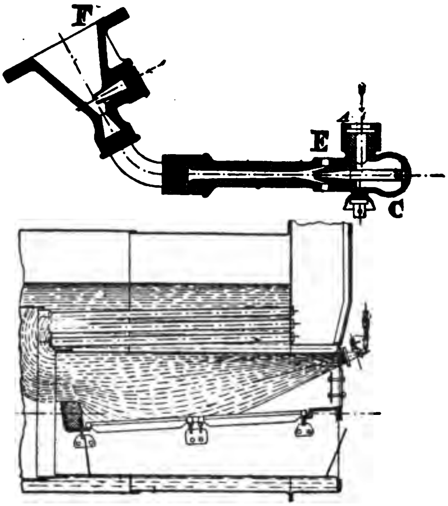


FIG. 9.—Körting's nozzle-sprinkler ; and, 10, arrangement of furnace.

Since 1886 the burner used by Körting has been that reproduced in fig. 11. This sprayer is very similar to that of Aydon and Selwyn, already described. The oil flows out of the slit-like openings, and is vaporised by steam jets, which meet it at an acute angle. The steam jets, which issue from orifices of from ·04 to ·08 inch in diameter, are together somewhat broader than when tar was employed. Should the nozzle get stopped up, the plug C is taken out, the supply turned off, and the nozzle cleaned out with the needle D.

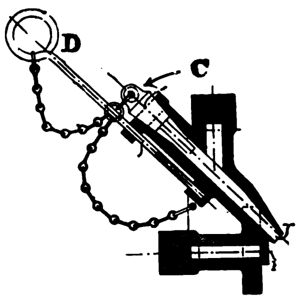
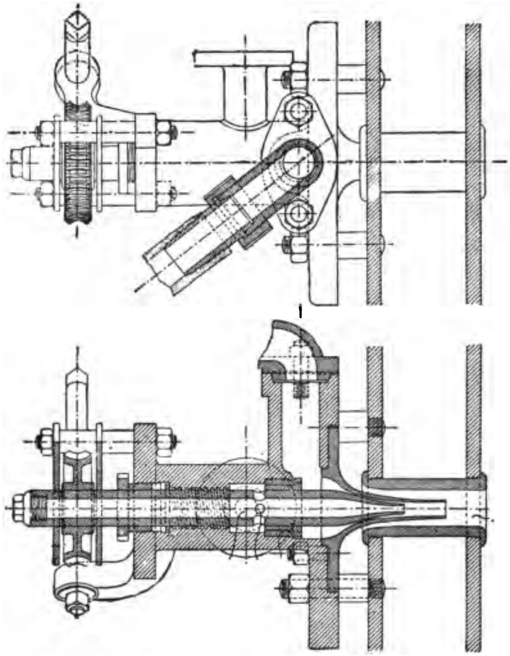


FIG. 11.—Körting's third burner.

Professor Urquhart's first liquid-fuel burner was experimented with on the Griasi-Tsaritsin

Railway in Russia; but owing to the large consumption of oil involved, the system was relinquished.

Between 1882 and 1885 Urquhart's latest nozzle-sprinkler (figs. 12 and 13) was introduced. In this the oil is conveyed from the tanks in the tender by means of a tube and a pipe into the burner. The non-superheated steam leaves the dome of the boiler and enters the latter; it passes through orifices into the interior of a bronze spindle, and escapes through the front of the nozzle. A spiral wheel which moves on a spring in a groove regulates the outlets for the oil residuals. To obtain the requisite amount of air the burner is fixed so as to extend into a pipe-rest, and a space of about 1 inch is allowed between the flange of the sprinkler and the plate of the boiler. The oil and steam are separated inside the sprinkler by means of a box



FIGS. 12 and 13.—Sectional views of Urquhart's burners.

filled with asbestos packing, which has to be renewed about once a month. The admission of steam is regulated by a special valve in the pipe. Professor Urquhart, after making numerous experiments with these burners in 1884, found that, by using oil for his locomotives instead of coal, a saving of 53 per cent. could be effected. In locomotives burning anthracite, and with a steam pressure of 8 atmospheres, from 7 lbs. to 7½ lbs. of water was evaporated by 1 lb. of anthracite; whereas 1 lb. of oil evaporated from 11·35 lbs. to 12·25 lbs. of water. As a result of this, 143 locomotives were fitted with this system on the above-mentioned Russian railway as early as 1885.

Should the burner get stopped up, the spindle has only to be screwed back, and the oil will force the carbonised particles into the fire-box. Urquhart also protected the walls of the pipe against the flames, and prevented the deteriorating effect on the boiler which their direct action would entail, by lining the inside of the furnace (fig. 14) with fire-brick. The sprinkler is fixed rather low, and blows into a furnace chamber built into the fire-box and covered with a vaulted roof which slants off in the direction of the tube-plate. The brickwork stands out from the wall of the fire-box about 2 inches, so that these walls are not lost to the heating surface. The flames beat from the furnace chamber against what was previously the fire-door, and which has been bricked up, leaving only a peep-hole. Two channels are built into the walls of the furnace chamber, and lead a portion of the heating gases to the lower surface of the tube-plate, as well as into the spaces between the brickwork and the outer walls of the fire-box, so as to give these a larger heating surface. The requisite

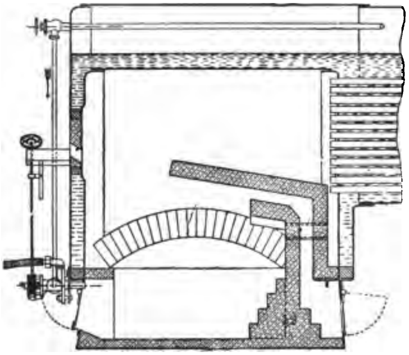


FIG. 14.—Arrangement of fire-box for Urquhart's burner.

amount of air is forced into the furnace by the burner, and more air is admitted by the ash-pan dampers, which are regulated by chains and chain wheels. The air entering at the front ash-pan damper passes through a channel, and is warmed before being admitted to the gases. Complete combustion of the oil is insured by fitting the fire-box with tiles, which, being non-conductors of heat, keep the walls of the fire-box at an equal temperature, and even relight the oil-stream should it have a tendency to become intermittent.

The burners introduced by M. Jules D'Allest, chief engineer of the Cie. Fraissinet of Marseilles (figs. 15, 16, and 17), were the outcome of an express wish on the part of the French Ministry of Marine to obtain a burner suitable for use on torpedo-boats. The experiments made with these burners, therefore, form an interesting link in the general development of liquid fuel, while they were probably the most exhaustive which had been carried out up to that time. The first burner consisted of a conical chamber of bronze, to which the liquid was conducted through a tube. Through the chamber into which the petroleum was admitted ran a spindle or small shaft, which was operated from the end by a small handle; the top of this spindle filled the orifice at the mouth of the burner. When drawn back, an annular opening was shown, varying between 0 and 2 mm. Through this annular opening the petroleum

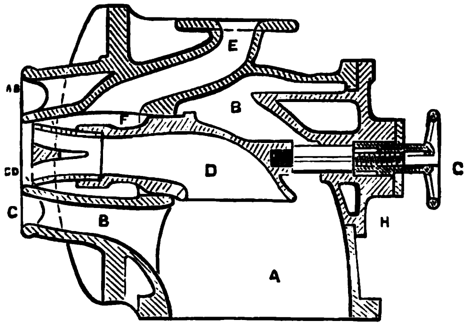
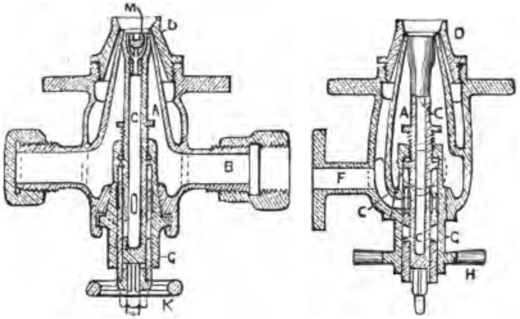


FIG. 15.—D'Allest's burner, using compressed air.

passed into the furnace in the form of a hollow cylinder. The steam, led to the sprayer through a pipe, surrounded the oil chamber, heating the contents, and, escaping in a stream of cylindrical form, enclosed the petroleum, and reduced it to spray, projecting it thus into the furnace. The force of the fire was regulated by the valve, which could be moved backwards or forwards, either diminishing or increasing the quantity of hydrocarbons introduced into the furnace. The burners are said to have worked well, and consumed between 10 and 80 kilos. of petroleum per hour. Two of these sprayers evaporated 2080 litres of water per hour.



Figs. 16 and 17.—Sectional views of D'Allest's burner for use on torpedo-boats.

If the evaporation amounted to 30 litres of water per square metre of heating surface, this would correspond to a furnace having a heating surface of 69 square metres.

In order to obtain a larger evaporation per heating surface than was here the case, a second jet of steam was introduced inside the oil jet. Thus, the oil came out enclosed by two pulverising streams, which broke up the former to a much greater extent and produced more perfect combustion. Experiments were made with a view to comparing results with natural and forced draught, and M. D'Allest gave two interesting tables, from which the following are reproduced:—

WITH NATURAL DRAUGHT.

	No. of Experiment.			
	1	4	6	10
Duration of experiment, hours	4·15	3·06	6·28	5·20
Consumption of oil in kilos.—				
Total	260·29	183·74	382·78	336·85
Per hour	61·24	59·27	59·19	63·16
Per sq. m. of grate surface per hour	69·57	67·34	67·24	71·76
Temperature of feed water	23°	28°	28°	28°
Pressure in boiler, kilos.	3	...	...	...
Water evaporated, kilos.—				
Total	3100	2100	4425	3900
Per hour	729	677	684	731
Per sq. m. heating surface	37·38	34·71	35·07	37·48
Per kilo. of oil	11·90	11·42	11·55	11·57
Same reduced to 100°	13·81	13·15	13·30	13·32

The fuel used in this case was Russian astatki.

WITH FORCED DRAUGHT.

	1	2	3
Duration of experiment, hours	1·30	4·30	6·00
Consumption of fuel—			
Total, kilos.	213·92	608·44	784·68
Per hour	142·61	135·21	130·78
Per sq. m. of grate surface per hour (surface as in torpedo-boats of 525 h.p.)	375	350	344·16
Temperature of feed water	16°	18°	17°
of smoke-box	350°	302°	380°
of air chamber	25°	20°	28°
Pressure on boiler, kilos.	3	...	...
Water evaporated—			
Total, kilos.	2200	7119	9432
Per hour, kilos.	1464	1582	1572
Per sq. m. heating surface, kilos.	73·20	79·10	78·60
Per kilo. of fuel	10·27	11·70	12·02
Per kilo., reduced to 100°.	12·01	13·68	14·06
Pressure of blast—			
In supply box, mm.	45	24	45
In tube box, mm.	10	8	8

This last table, remarks D'Allest, shows that the use of petroleum with forced draught evaporation reaches extremely high limits, and a great deal higher than those that can be obtained with coal. It is also noticeable that, by increasing the supply of petroleum and air into the furnace, a still greater evaporation would have been obtained. With the use of coal on torpedo-boats of this size, 800 kilos. of fuel evaporated only 6·5 to 7 kilos. of water per kilo. of coal.

The engineer then works out a comparison of the evaporative power of coal-burning and petroleum-burning boilers. In a boiler burning coal, he says, to consume a kilo. of combustible there must pass into the uptake 10·64 m.c. of products of combustion to evaporate the maximum of 8 litres of water. In a boiler burning petroleum, however, to burn the same quantity of combustible it is necessary to consume 14·36 m.c. of the same products; therefore, 13 litres of water are evaporated. In other words, to evaporate a litre of water it is necessary with coal to circulate in the boiler

$$\frac{10\cdot64}{8} = \text{m.c. } 1\cdot330 \text{ of air,}$$

and with petroleum,

$$\frac{14\cdot36}{13} = \text{m.c. } 1\cdot104\,;$$

or, for the circulation of 1 cubic metre of gas in the flue, the boiler evaporates, employing coal,

$$\frac{1}{1\cdot330} = \cdot75 \text{ litre of water,}$$

and with petroleum,

$$\frac{1}{1\cdot104} = 0\cdot90 \text{ litre.}$$

The result of this is that, with equal sections of tubes, and consequently equal heating surface, and with the same conditions of draught, with naphtha the same boiler evaporates

$$0\cdot90 - 0\cdot75 = 0\cdot15, \text{ whence } \frac{0\cdot15}{0\cdot75} = 20 \text{ per cent. more than coal.}$$

It therefore also follows that to evaporate the same quantity of water in a unit of time with the same draught, the petroleum boiler can be 20 per cent. smaller than the coal-burning boiler. Now, a still greater difference has been found in practice, caused by the fact that in burning coal there is introduced into the furnace a much greater quantity of air than is theoretically necessary, while with petroleum, on the contrary, this quantity of air is reduced, on account of the intimate union of the combustible and the supporter of combustion, and on account of the uniform flow of the two, all which brings the combustion nearer the theoretical conditions. This observation, and the comparison previously made between the products of combustion in the two cases, explain the considerable evaporation that has been demonstrated in the experimental boiler.

M. D'Allest also deals in the same paper with the use of compressed air for pulverising the oil instead of steam. He remarks that on a torpedo-boat, the water supply being limited, it would be inconvenient to employ steam, and looks favourably on air as a substitute. The air must, of course, be heated to about 50° or 60° C. Compressed air, however, was not a new idea even at the time of M. D'Allest's experiments, as a French company, the Forges et Chantiers de Marseilles, experimented with an air pulveriser imported from Russia previous to 1883. M. D'Allest does not, however, seem to have taken into consideration the additional space that would be occupied by the air compressor, which is a disadvantage on such a vessel as a torpedo-boat.

Thus we are brought down to the year 1883, which may be said to mark the commencement of a fresh period in liquid-fuel progress, as we now reach the era inaugurated by the burner introduced by Mr James Holden, locomotive superintendent of the Great Eastern Railway, who has devoted so much time to the problems of liquid fuel burning, and whose improvements will be dealt with in the following chapter.

CHAPTER VI.

MODERN BURNERS AND METHODS.

SINCE the year 1883 the progress of oil as fuel has been more rapid than in its previous history. This has been due to the greater attention paid to the engineering problems connected with its use, and to a recognition of the difficulties which had to be removed in order to obtain a good combustion and to prevent the deposition of carbon in the tubes and other parts of the burner. It was further recognised that the burner is not the only important consideration in the burning of fuel oil, and that the arrangement of the furnace itself meant either a proper utilisation of the heat generated or a waste of energy and money.

It was about this time that Mr James Holden, locomotive superintendent of the Great Eastern Railway, turned his attention to the use of liquid fuel for steam-raising. The first kind of fuel that he employed was the waste tar that he obtained from the oil gas works at Stratford, for which Mr Holden set about inventing spraying apparatus. His purpose was to devise one which would be independent of any extra brickwork, and also should be available for use in conjunction with coal, and he ultimately introduced a system by which it became possible to fire a boiler either with coal alone, as ordinarily used, with coal and oil combined, or with oil alone.

Such an arrangement, of course, possesses great advantages over those where special treatment of the furnaces is required, for, as the ordinary grate remains, steam can be raised with wood or coal.

In the early days of oil-firing experience, Mr Holden discovered that ordinary jet burners could not be relied on to efficiently spray oil enough for the generation of sufficient steam without the brick arrangements objected to, and a new burner was therefore devised with many improvements in it.

The burner for locomotive work in its latest form is shown in figs. 18 and 18*a*. It consists, primarily, of a coned body AA, to the interior of which the oil fuel is admitted through a specially-designed regulating valve BB. Inside the body an annular steam jet D is introduced, possessing a central passage for assisting in the supply of air, and also for enabling a wire to be passed through the burner without shutting off either oil or steam. At the front, immediately behind the nozzle, a hollow ring CC is attached, and to this steam is admitted and allowed to escape from six very fine jet holes. It is the provision of this ring and its arrangement that enables the "Holden" burner to dispense with the brick walls which are necessary with other devices for atomising and distributing oil fuel. Another requirement fulfilled by this steam ring is that the jets induce a strong current of atmospheric air, which is carried forward and mixed with the spray as it emerges from the nozzle, ensuring complete combustion. The steam supplied to the ring is conveyed through a branch from a small regulating valve attached to the rear of the burner, so that only one pipe is required from the boiler; the small jets in the front of the ring are at such angles as have been found to most thoroughly split up the oil.

The valve BB used for regulating the flow of the oil fuel is of special construction, and in the Holden burner a small reservoir of oil is formed by the body of the valve, a tube with a slit in it being moved up and down inside. With this valve very fine adjustments in the flow of the oil fuel are possible.

In the case of the burners adapted to stationary boilers the main supply of fuel is first admitted by turning the wheel F. Should an increased quantity be required, it is provided by opening the valve actuated by the wheel E, and as the fuel issues from the hole on the top of the nozzle it is atomised by the steam from the ring and centre cones. By this arrangement a larger portion of oil fuel can be injected, sprayed, and atomised without increased consumption of steam. The steam supply to the ring on the injector is regulated by the small cock G.

One advantage of the Holden system for stationary boilers is that, when the main valve is closed, the auxiliary supply is also cut off.

Further illustrations (figs. 29 and 35) are given of the Holden burner, which is also referred to in the chapter dealing with liquid fuel on railways. There can be no doubt that a great deal of the progress of this form of fuel is due to the time and thought Mr Holden has expended in perfecting the burner which bears his name. It is now used extensively on the Continent and in other parts of the world. On the Austrian State Railways alone the sixty-eight loco-

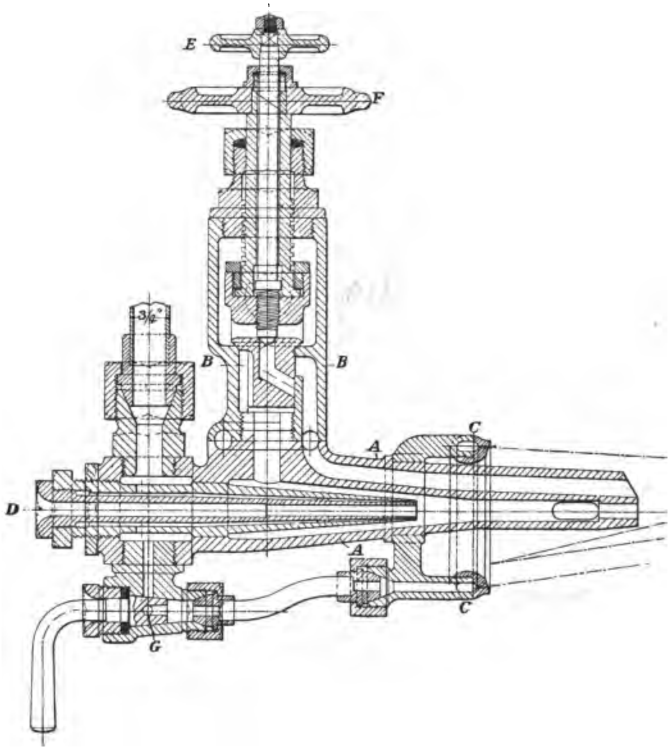


FIG. 18.—Holden's oil-fuel burner for locomotives.

motives which are running on liquid fuel are fitted with the Holden system. It is on this line, upon which the six-mile Arlberg tunnel occurs, that such excellent economic and chemical results have been achieved. In the first instance petroleum and coal were used conjointly, but latterly oil alone has been employed.

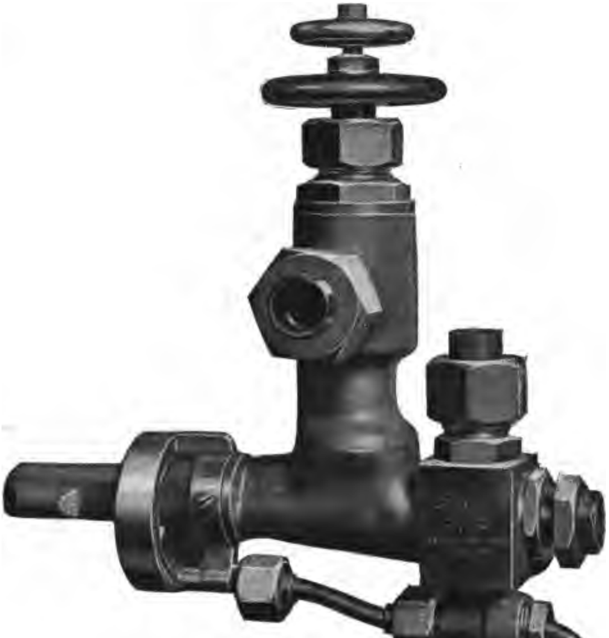


FIG. 18*a*.—General view of Holden's burner.

In addition to Mr Holden, a number of firms and individuals have devoted a considerable amount of time to the subject of improving existing methods of burning oil fuel. Messrs Kermode of Liverpool, Messrs Körting, Mr

E. L. Orde, of Messrs Armstrong, Whitworth & Co., Messrs Rusden and Eeles, among others, have all introduced special forms of burners, which are illustrated herewith.

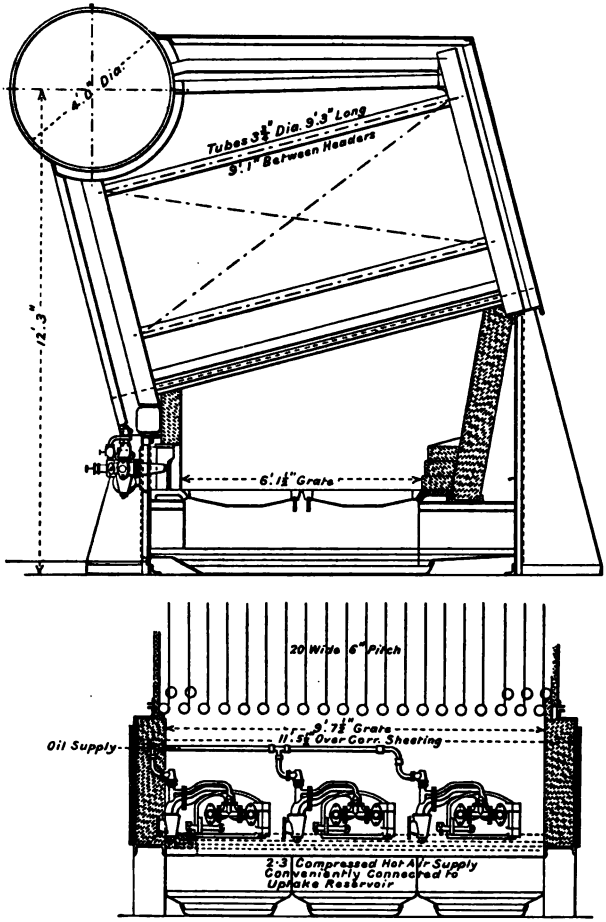

4'.0" Dia.
Tubes 3¼" Dia. 9'.3" Long
9'.1" Between Headers
12'.3"
6'.1½" Grate
20 Wide 6" Pitch
9'.7½" Grate
11'.5½" Over Corr. Sheeting
Oil Supply
2·3 Compressed Hot Air Supply
Conveniently Connected to
Uptake Reservoir

FIG. 19.—Babcock and Wilcox marine type boiler, arranged for the Kermode system.

The first of those mentioned, that of Messrs Kermode (fig. 19), has the following characteristics. The oil supply is obtained from an elevated tank, flowing by gravity to the burner, with which the pipe is connected by a plug and cone. The burner itself contains an inner tube through which both oil and air pass. The tube contains a screw device, which is an extension of the valve employed for regulating the supply of oil and imparting a whirling motion to the oil. The outer casing is spirally grooved, which gives a rotatory movement to the air.

The Körting burner (fig. 20) differs from others in that the pulverisation is direct, that is, the oil is forced merely by pressure through the burner. The oil is first heated to a temperature of 130° C. and then is forced through the burner under a pressure of 50 lbs. to the square inch. The oil flows into a chamber feeding the jet, and this jet is, as will be seen from the accompanying sketch, fixed to a spindle carrying a spiral screw. The oil is forced down this spiral, acquiring a centrifugal movement, which sprays it out of the jet in a very finely divided state.

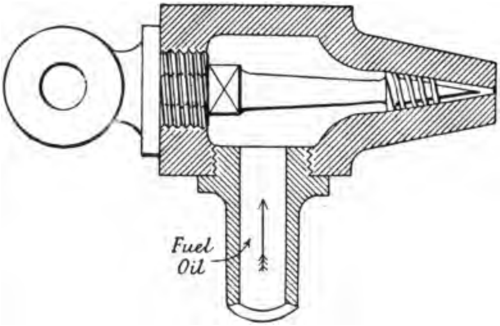


Fig. 20.—Körting's burner.

This simple method has many points to recommend it, and has been employed with very satisfactory results on vessels of the Hamburg-American line.

Another form of steam pulverising burner largely used in practice is that designed by Messrs Rusden and Eeles (fig. 21), one of the burners employed on the vessels of the Shell line. In this burner, oil, after having been heated by means of a steam jacket, is sprayed out by the steam, and as the burner is so made as to allow of separate adjustment of the steam and oil jets, the consumption of the fuel can be easily controlled to the special work it has to do.

In the burner designed by Mr E. L. Orde (fig. 22) highly superheated steam is employed, 600° F. being the temperature at which it probably works best. The steam is so arranged as to sweep out and spray the oil at a very high velocity, thus inducing a current of hot air in conjunction with the steam and oil.

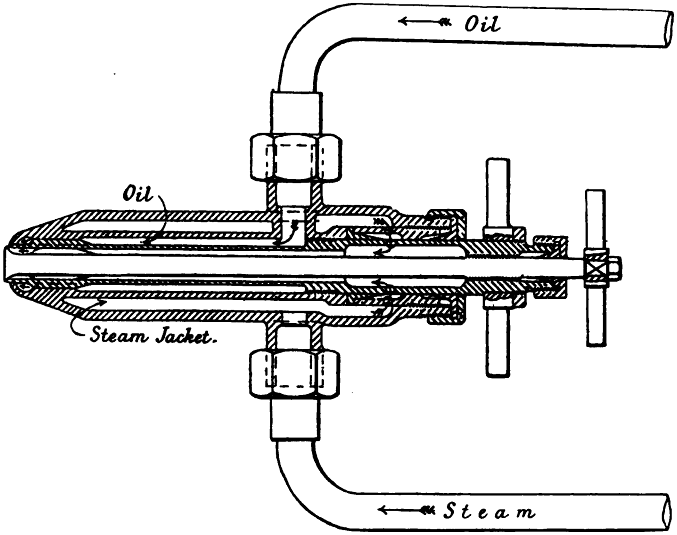


FIG. 21.—Rusden and Eeles' burner.

In addition to these systems there is that of Swensson (fig. 23). In this, as in the Körting burner, the oil is merely forced into the burner by pressure, having been previously heated in a steam-jacketed tube. The oil passes through a fine jet on to the point of a V-shaped metal cutter, which has the effect of pulverising it in very fine spray.

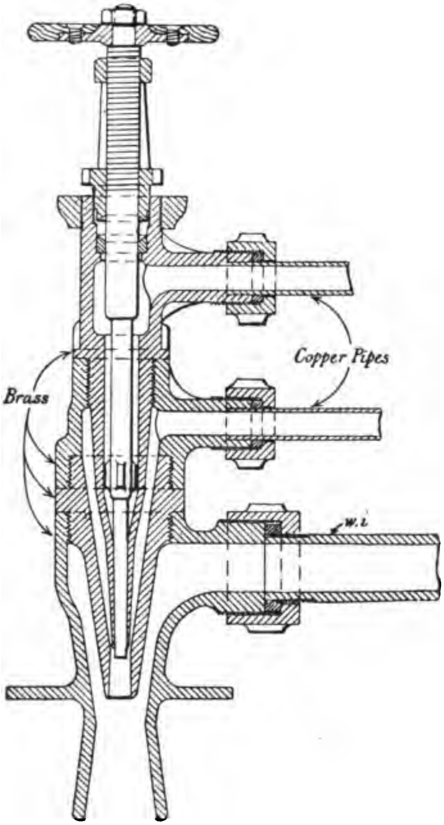


Fig. 22.—Orde's burner.

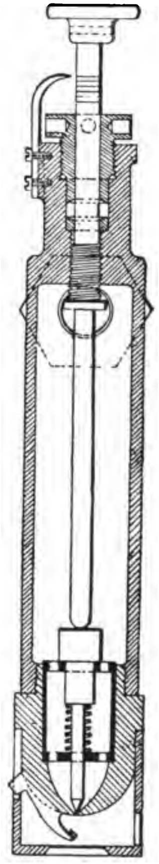


Fig. 23.—Swensson's burner.

Mention may also be made of the Dürr system (fig. 24). In this apparatus, the oil is supplied by air pressure through a heated retort, in which it is vaporised, and the vapour is then gasified in a chamber in the mouth of a furnace heated to a high degree. The gas is led straight for combustion into the furnace.

The number of new oil burners introduced in different parts of the world is far too large to refer to all here. Several burners used in the American naval tests are illustrated and described in the chapter dealing with naval work. They are, however, in principle similar to those described and illustrated here, or are some modification of them. At the same time, it cannot be said that the

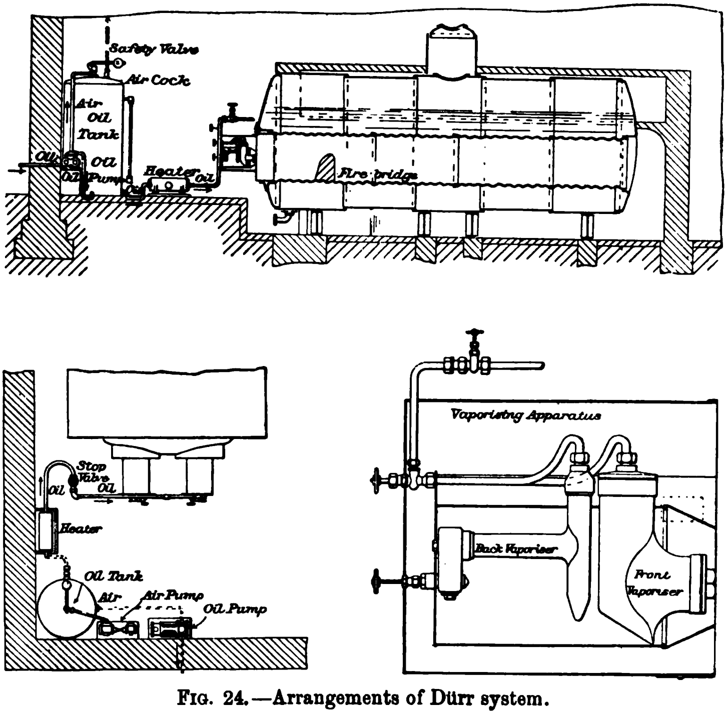


FIG. 24.—Arrangements of Dürr system.

perfect oil burner has yet been found, though very great advance has been made in that direction.

For the successful use of liquid fuel it appears to be a *sine qua non* that auxiliary apparatus and extraneous sources of heat must be avoided, and the furnaces made practically self-contained, if anything approaching perfection is to be attained. It must be upon simplicity, ease of working, and freedom from complicated parts that the progress of liquid fuel must chiefly depend.

The direct pulverisation of the oil is now coming to be recognised as the proper method; it is the most efficient and the most economical.

CHAPTER VII.

OIL FUEL FOR MARINE PURPOSES.

DURING the last few years the application of oil fuel for marine purposes has received very considerable attention from all the leading countries of the world. The chief impetus for this movement was received from the Shell Transport and Trading Co., nearly the whole of which company's vessels are run on this description of fuel. The original source of this application is no doubt the extensive use which oil fuel finds on the steamers of the Caspian Sea, and which began as far back as 1870. The burner employed was that introduced by Shpakovsky, who was the first to use steam as a pulverising agent. Later on, however, the Caspian Sea fleet was fitted with the Lenz burner, a description of which has already been given. This was no doubt the starting-point of the fitting out with liquid-fuel burners of those vessels which have since adopted it. The vessels include, in addition to the Shell Line Co.'s fleet, the Netherland, the North German Lloyd, the Hamburg-American, the China Mutual, and the East Asiatic Companies, though none of these use it on so extensive a scale as the first-named company, which has between thirty and forty vessels burning liquid fuel. The Messageries Maritimes, the largest French shipping company, are also like to adopt oil as fuel very shortly, it having been strongly advocated by the president, M. André Lebon. The application of oil fuel to the marine services offers greater difficulties than its use in stationary engines and locomotives, and consequently the experiments made in different parts of the world have been more varied, more especially as the conditions governing its use in the two branches of the service, the mercantile and the naval, differ considerably. So greatly is this the case, that arrangements which are suitable to a merchant ship are quite useless when applied to a battleship, and the reasons for this will be apparent when the following data and descriptions have been perused.

As the application of oil fuel in the two branches of the service differs so radically, each will be dealt with separately. The chief advantages, however, which are common to both, as has already been pointed out, include the great reduction of stokehold staff, ease and regularity of working, cleanliness, rapidity of loading up the supply of fuel, saving in space occupied by fuel, and augmented accommodation for cargo, passengers, or crew. An advantage of liquid fuel pointed out by Sir Fortescue Flannery, M.P., is in the matter of stoking. Some of the great American liners, he says, experience a difficulty in maintaining their full-power speed as compared with the performances when the ships are new. This is not due to a deterioration of boilers or machinery, or to the quality of the coal, but to a difficulty in getting the trimming and stoking done to the fullest capacity of the boilers. Such an obstacle would not be present in the case of liquid fuel being used.

For a record of experience on a merchant ship, we cannot go to a better source than to the officers of the Shell Line Co., under whose auspices much has been done to advance the claims and development of oil fuel. The writer had the privilege of visiting one of these fine vessels, the *Cowrie*, and in an interview with the captain and the engineer, gleaned much important and interesting information, which was printed in the *Petroleum Review*, and is reproduced here as being an excellent *résumé*, not only of the advantages of the fuel, but the difficulties which had to be encountered.

The words in which Captain Davies of the *Cowrie*, in a comparison of liquid fuel with coal, expressed his views, were that, in a way, it was much easier to work, much cleaner, reduced the number of stokers, and maintained more equable heat.

Mr Buck, the chief engineer, who had practical experience in the working of the fuel during the voyage, said that liquid fuel may generally be described as much preferable to coal. Leaving Balek Pappan with 670 tons of liquid fuel in the bunkers, they set out on their journey. The various trivial circumstances always attending first efforts were not wanting on the *Cowrie*. It was only, however, a question of becoming familiar with the new appliances and methods of working, and these once thoroughly mastered, there could be no doubt of the superiority of the one fuel over the other. For the purpose of replenishing its exhausted bunkers, the steamer called at Colombo and took in a further 350 tons of liquid fuel, and an additional 630 tons again at Suez. At both of these places the oil was obtained from the company's own storage tanks. This brought the boat to London, and left a balance in the bunkers of about 150 tons The burners used on the *Cowrie* are of the Holden type, and therefore need no detailed description here.

But as those who have used liquid fuel know full well, it is not only the burner on which good and economical working is dependent, but also upon the arrangement of the furnace itself. The difference between burning coal and using oil is that with the former it is possible to get a very extended heat-surface, while the tendency with oil is to concentrate the heat too much. To overcome the difficulty, certain dispositions of fire-brick in the furnace are made. The special method which had been adopted on the *Cowrie* was as follows:—The column and bridge of fire-brick, which are usually placed above the centre of the grate, and under the arch, so as to break up the flame as it comes from the burner, has one defect, in that, although it splits up part of the flame, it allows a considerable portion to fly over the bridge in one unbroken mass. To remedy this defect, Mr Buck carried the column of fire-brick supporting the bridge to about the same height above, so that the flame is split up to a much greater extent. In addition to this, he built up at the back of the boiler another partition of fire-brick, having four holes left by the omission of four bricks in it, which again effects a more thorough splitting up of the flame. He found that the system worked very well.

One of the points brought out in the conversation with Mr Buck was the trouble of getting up steam. The difficulty lies in getting up steam too fast, as it is not easy to keep a small flame going, and the heat increases too suddenly. The only way of obviating this is to ignite the burner intermittently; that is to say, if you light up at 7 o'clock, shut off at 7.30, at 8 o'clock light up again, shut off at 8.30, and continue this until the vessel is ready to start.

Another point in connection with liquid fuel elicited from Captain Davies was that from the point of view of economy something remains to be done in regard to the burner. "If we could save the 4 or 5 tons per day," he remarked, "which it is necessary to use to provide the steam for pulverising the oil, it would be a great thing." His idea was that improvement lies in the direction of hot air, and it is interesting to note that the boats of the Dutch line plying between Singapore and Batavia have a system of hot air in use, which is described later.

An interesting comparison may also be made with the *Cowrie* on her last voyage, burning oil, and on a previous trip while burning coal. From Port Said the time occupied while burning liquid fuel was only 14¾ days, whereas, while burning coal, the time occupied between Port Said and London was 16 days.

The consumption of liquid fuel on the steamer may be put at about 26 tons per day, compared with a consumption of from 30 to 32 tons of good Welsh coal. On the *Cowrie*, wherever motive power is required, oil is the fuel that produces it; there is absolutely no coal used. The pumps for pumping out oil from the tanks are driven by it, the donkey boilers for general purposes are heated by it, and the capstan, winches, and the steering gear are entirely worked by it.

Other interesting data in connection with the mercantile service are provided by the record of experiments made on the Roumanian mail steamer *King Charles I.*[1] towards the end of 1901.

The *King Charles I.* runs between Constantza and Constantinople, and is capable of carrying 60 first, 60 second, 300 third class passengers, and 400 tons of merchandise.

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[1] *Moniteur des Intérêts Petrolifères Roumain.* Translation in *Petroleum Review.*

Length of steamer	350	feet.
Gross tonnage	2360	tons.
Net tonnage	839	,,
Bunker capacity	400	,,
Maximum speed	19	knots.
Total h.p. of engines (two vertical triple expansion with surface condensers) .	6500	i.h.p.
Revolutions per minute	150	
Heating surface of boilers (four boilers of marine type, of which two are ordinary boilers with four furnaces and two double ones with eight furnaces each) .	5800	feet.
Pressure of boilers	12½	atmos.

For the purpose of using the new fuel the vessel was fitted with all the necessary accessories. As a measure of prudence, during the experimental period of one and a half months the petroleum fuel was only used under one boiler, the other continuing to burn coal.

The oil was stored in the water ballast tanks, the supply of oil which the vessel could take in these tanks being 280 tons. A Worthington pump served for raising the oil from the tank into two elevated reservoirs installed above the boilers. From these reservoirs the oil flowed by gravitation to the petroleum injectors or pulverisers. In the tanks, as well as in the elevated reservoirs, the petroleum was heated by a steam coil.

Each furnace was provided with a petroleum pulveriser on the Wolff system.

After the experiments with the one boiler were completed, all the boilers in the vessel were adapted for burning the new fuel, and since then the *King Charles I.* has used nothing but petroleum residuals in her furnaces. The installation has received certain additions and modifications. The chief of these is that the pipes through which the condenser water from the tanks and the elevated reservoirs was conducted, and which at the beginning were arranged in such a manner as to conduct the water into the condensers, thus realising an economy of from 2 to 3 per cent., were rearranged in such a manner that the condenser water discharged itself into the hold of the vessel, thus renouncing this economy for the sake of greater safety. Such a measure was considered necessary, because the coils, which, by reason of their length, were made up of several pieces, did not remain perfectly tight, and the oil penetrated through the coils and condensers into the boilers, where the presence of petroleum is a serious danger.

The internal arrangement of the furnaces was also modified, and whilst at the beginning matters were arranged in such a manner that the air required for combustion entered only from underneath the injector, it was subsequently arranged in a different manner. The air required for the combustion of the oil enters the furnace partly from below the injector and partly through holes in the bottom, which separates the furnace from the chamber in the rear. The air which enters through these holes has the effect not only of completing the combustion, but also of beating back the flame when a vacuum is formed occupying almost the whole furnace, and while abating the great speed of the flame, it prevents the formation of a white and powerful one, which might produce superheating of the parts at those points where they are not covered up with fire-bricks. The furnace is also refreshed by the air which enters it in a pre-heated state.

The writer of this record points out the following danger from carelessness of the crew in regard to closing the air valves when the furnace is not in use. When the fires are put out on the vessel arriving in port, if the valves for the admission of air into the furnaces are not closed hermetically, the cold air penetrates in large quantities into the furnace, and unequal contractions in the interior of the furnaces are caused, thus producing leakages in the smoke flues. It is therefore necessary on the one hand that the stokers should always take care when extinguishing the fires to close well the air admission valves in the furnaces, and on the other hand it is necessary that the installations should be made in such a manner that the hermetical closing should be the most perfect possible.

When coal was burned on board the *King Charles I.* there were three shifts of six stokers, or eighteen stokers in all. Since petroleum has been burned only six stokers are required, and even these have but light work.

With coal the consumption of fuel on the vessel was about 150 tons of Westphalian coal per voyage—that is, from Constantza to Constantinople and back, plus the consumption while in port.

The consumption of oil fuel for the same trip amounts to between 70 and 80 tons of petroleum.

It is estimated that the total economy which can be secured on the *King Charles I.* by burning petroleum instead of coal may amount to 100,000 francs per annum, if the price of petroleum does not exceed 40 francs per ton.

The Dutch steamer to which reference was made above is a vessel belonging to the Koninklijke Pakewaart Maatschappij, of which Mr R. A. Meyer is the superintending engineer. He is also the inventor of the system used in this company's steamers, and which is described below.

With the object of overcoming the difficulties consonant with the use of steam for pulverising purposes, Mr Meyer set himself to solve the problem, with the result that he adapted for sea-going steamships the system of injecting the oil into the furnaces under pressure by a common steam or donkey pump, while the exhaust steam of this pump is returned to the main condenser, thus avoiding the loss of fresh water.

On its way from the oil tanks to the donkey pump, and from there to the nozzles in the furnace fronts, the oil is heated and filtered by an arrangement as shown on the opposite page.

The other illustrations (figs. 26 and 27) show the arrangements of the burner and of the furnace.

In fig. 25, A is a valve box with suction pipes from the oil tanks and connections to pump the residuals from one tank to the other.

B is a heating apparatus which heats the residue slightly by the exhaust steam of the donkey pump on its way to the condenser, thus rendering it more fluid.

C is a filter for cleaning the residuals of dirt; C′ is a reserve filter to be used while the filter C is cleaned; D is a donkey pump; D′ is a reserve donkey pump, to be used in case of repairs to pump D; E is a heating apparatus to heat the residuals to 200° Fahr. with the live steam on its way from the boiler to the donkey pump D; F is a pressure gauge, showing the pressure on the residuals; G is a thermometer showing the temperature of the residuals before they enter the furnace; H is a spring-loaded escape valve, regulating the pressure on the oil.

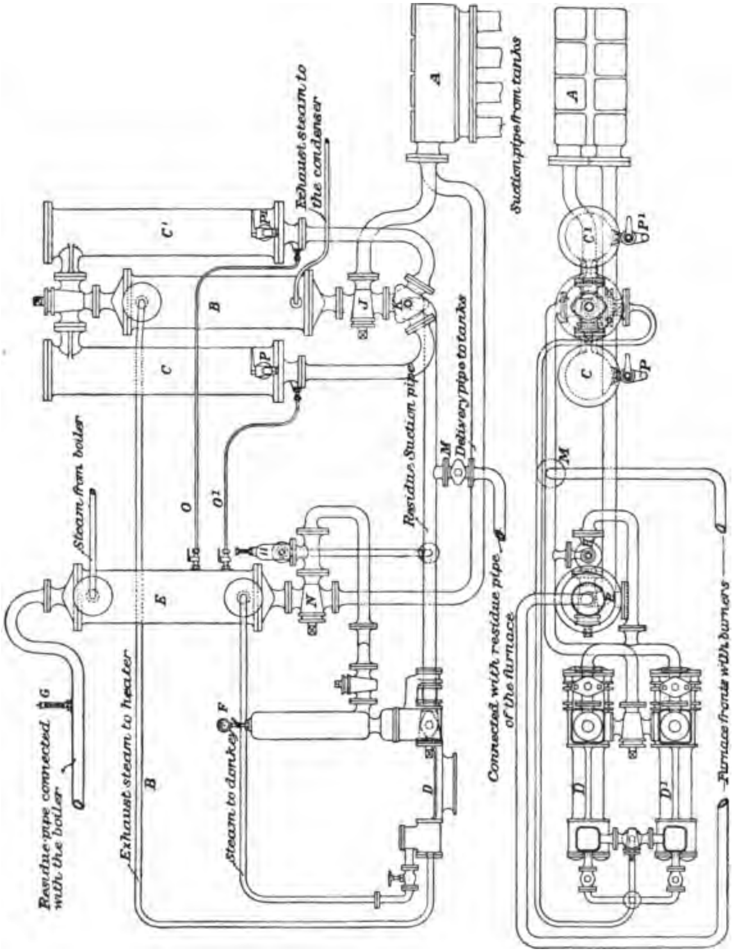


FIG. 25.—Arrangements for heating, filtering, and pumping liquid fuel on Dutch steamers.

To bring the residue to its proper temperature, before injecting into the furnaces, the hollow plug cocks J and N are opened upwards, and the three-way hollow plug cock

K opened to one of the pipes coming from the filters. The cock M is opened also, all stop valves on the injectors shut, and the donkey pump D or D′ started.

This now draws the fuel from the valve box A, through the cock J, heater B, filter C or C′, and hollow plug cock K, and forces the residue through cock N to heater E, and from there through the delivery pipe, which is now in connection with the suction pipe through the cock M, thus circulating the fuel through the heaters and filter.

As soon as the thermometer G shows the required temperature, about 200° Fahr., the cock M is closed, and the stop valves on the injectors opened, the heated fuel now spraying into the furnaces, where it is ignited by a common torch. The small steam-pipes O and O′ serve to blow steam through the wire gauze inside the filters for cleaning purposes, the dirt being discharged through the drain cocks P and P′.

In constructing the heating apparatus B and F great care must be taken to make the joints between oil and steam spaces in such a manner that no possibility exists for the residuals to leak into the latter, which might occur in the event of the residuals being under higher pressure than the surrounding steam.

In such case the oil would go with the steam into the condenser, and from there into the boilers, which might lead to dangerous results. It is better to have as few joints as possible between these two spaces.

With the above method of injection, however, another medium has to replace the steam of the steam jet to break up the residue into small particles when entering the furnace, and for this reason, instead of the common orifice, a Körting injector is used, which, on account of the screwed needle inserted in this apparatus and of the pressure on the residuals, gives the latter a great centrifugal velocity, which causes a more perfect breaking up of the residuals as soon as they leave the injector. The small size of the delivery hole of this injector (no more than $\frac{1}{32}$ of an inch in diameter), compared with the large capacity of the donkey pump, causes the pressure on the residuals. Any other kind of injector, however, may be used, provided it gives the same results.

In arranging an ordinary furnace of a marine boiler for the burning of liquid fuel, Mr Meyer emphasises the following points:—

First.—With a single Körting injector no more than a quantity of oil sufficient for about 80 I.H.P. per hour can be injected into the furnace (enlarging this injector would infringe upon its good working), and this often renders it necessary to place two and sometimes three injectors on each furnace to allow the full quantity of fuel, necessary for the generation of the steam wanted, to enter the furnaces, and ample room should thus be given on the furnace front as well as in the furnace itself to allow for these injectors.

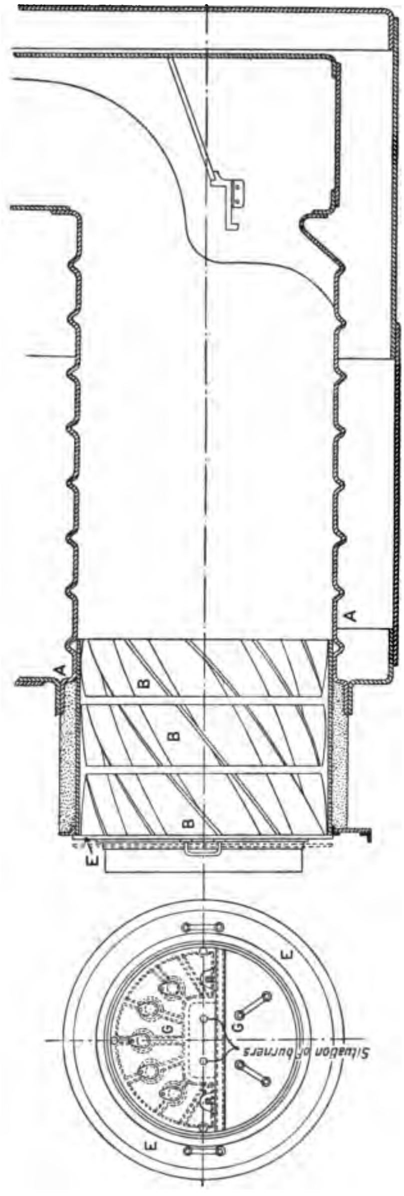
Second.—The air necessary for combustion, about 200 cubic feet per pound of residuals, has to be well heated before coming into contact with the particles of fuel, and this contact should be as complete as possible, to allow every particle to be well surrounded by the hot air flowing in. Care should be taken to let the fresh air from without obtain free access to the furnaces, and therefore the stokehold gratings on deck should be made large and in accordance with the quantity of air necessary for combustion.

Third.—To ensure proper contact between the air and the fuel, the air flowing in should surround the injected residuals on all sides in the furnace.

Fourth.—The jet of oil should spray freely into the furnace and burn there without touching any of the boiler parts or brickwork, as this would cause the formation of solid carbon.

Fifth.—A good quantity of brickwork is necessary in the furnace, not only to act as a bridge to prevent the gases from escaping unburnt through the funnel, or as a protection for the back of the combustion chamber, but also to allow the brickwork, after being heated, to work as a heat accumulator, which is necessary to keep the furnace at a high temperature.

Sixth.—The opening of the fire-bridge for the outflow of gases should be tried very accurately, as an opening too small or too large would produce a dense smoke. Experience with Borneo oil showed 0·6 square foot of opening per burner to be about the required size.



A.

B.

FIG. 26.—Meyer's system of furnace arrangement.

Taking the above points into consideration, Mr Meyer constructed a furnace arrangement as on annexed drawings (figs. 26 and 27), and patented it after a complete success under constant running on two sea-going steamers during one year and a half. These steamers have triple compound engines of 800 and 1350 indicated horse-power.

In this arrangement the common furnace front, dead-plate, fire-bars, and iron bridge are removed, and the heat of the burning fuel allowed to extend over the full circumference of the furnace.

In the front end A (fig. 26*a*) of the furnace is fitted an annular ring B, provided with metal strips C (fig. 27 *a* and *b*) secured edgewise upon and around its external surface so as to traverse it longitudinally, an interval space being left between each strip. These spaces form channels to conduct the air, which is heated by the fuel burning inside the ring. To delay the incoming air more or less in these channels, so as to give it ample opportunity to receive the heat, the strips are arranged so as to traverse the perimeter spirally. This ring is made in two or more short lengths, so as to facilitate its manufacture, the different lengths being kept somewhat apart, thus forming circular openings, through which part of the air enters and ignites the fuel inside the apparatus. The rest of the air comes into contact with the fuel on emerging from the end of the channels D (fig. 27*b*).

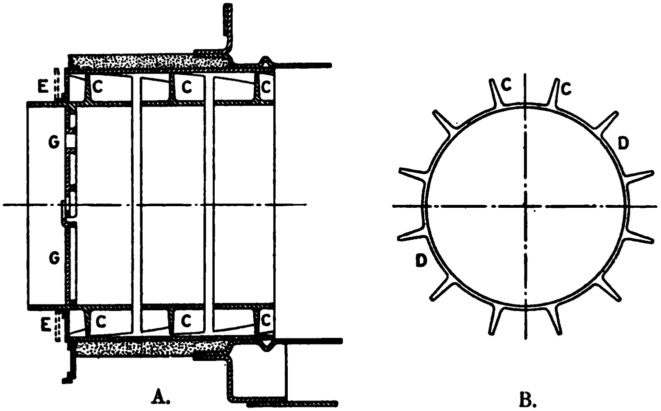


FIG. 27.—Meyer's system of furnace arrangement.

The annular space formed by these channels, by which the air enters at the stokehold side, is provided with a suitable damper properly guided and rendered adjustable, so that the amount of entering air can be nicely regulated.

In figs. 26 *a* and *b*, and 27*a*, E indicates the damper.

Inside the annular part of the arrangement for air inlet the conductor ring is closed at the stokehold side by a cover G (figs. 26*b* and 27*a*), which is made in two pieces, the fixed part carrying the injectors, the loose part giving opportunity for inside inspection of the furnace.

The oil pipes leading to the injectors are provided with stop valves near each injector, so that every burner can be put out of action without interfering with the others.

Some interesting experiments were also made with Texas oil under a marine boiler at the works of Messrs John Brown & Co., Ltd., Sheffield, at the beginning of 1903. The conditions of the test, which lasted three days, were as under:—

The boiler was 12 ft. mean diameter by 11 ft. mean length, fitted with two Purves furnaces 3 ft. 9 ins. inside diameter; heating surface, 1200 square feet, and grate surface (for coal burning), 43 square feet.

The furnace was fitted with the Ellis & Eaves system of induced draught, the surface in air-heating tubes being 800 square feet.

The quality of the oil used was Texas, closed flash point 185°. Tests were made in the company's works' laboratory, and by Professor Ripper of University College, Sheffield, of four samples of oil taken from supply tanks, and the calorific value of the oil after water was abstracted was returned as equivalent to 19·63 lbs. of water from and at 212° F. per lb. of oil. The specific gravity varied from ·938 to ·942.

The difference in left- and right-hand temperatures of air entering the fires is due to the fact that the right-hand air-heating box and air casings are protected from the weather by a wall, and also that the air entering is at a higher temperature, due to radiation from the fan discharge.

The test was started on Wednesday, the 18th February, at 11 a.m., the boiler being cleaned before starting, and was continued night and day till 9 a.m. on Saturday, the 21st February, the installation working without a hitch during the whole of that time. Burners were cleaned before starting, and worked throughout the test without further cleaning. Strainers were not fitted to the oil supply. Hot air only was admitted to the furnaces, the greater part of this being admitted round about the burners through vena-contracta nozzles.

The summary of the results obtained is given in the following table:—

	Average Steam Pressure (Gauge).	Average Steam Pressure to Burners.	Average Fan Revolutions per Minute.	Temperature of Heated Air entering Fires. Left.	Temperature of Heated Air entering Fires. Right.	Temperature of Gases entering Air Heater.	Temperature of Gases leaving Air Heater.	Temperature of Feed Water.	Total Quantity of Water evaporated, in Gallons.	Quantity of Water evaporated per hour, in lbs.	Total Quantity of Oil used, in lbs.	Quantity of Oil used per hour, in lbs.	Lbs. of Water evaporated per lb. of Oil, actual.	Lbs. of Water evaporated per lb. of Oil from and at 212° F.
1st Day	139	62	358	223° F.	242° F.	653° F.	457° F.	44° F.	26,800	11,166	21,168·3	882	12·66	15·44
2nd Day	140	63	370	245	260	714	495	44	26,660	11,108	21,832·6	909·6	12·21	14·9
3rd Day	141	63	379	267	267	817	528	44	25,470	11,576	20,847·6	947·6	12·21	14·9
Total .	140	62	369	245	256	728	491	44	78,930	11,275	63,848·6	912·1	12·36	15·09

These experiments are to be followed by a further series with compressed air as an atomising agent, and also with mechanical atomisation.

In the presence of the chief of the Roumanian Royal Navy and other officials recently experimental trips were made on the Danube with a paddle steamer belonging to Mendel Brothers. The fuel tanks had a capacity of 25 tons, and three oil furnaces were employed. These furnaces were lined with basalt bricks, and the burners were of the Holden type. The residuals were heated in the tanks to a temperature of 105° C., and then mixed with air heated to 260° C. before being introduced into the furnaces. The consumption of fuel amounted to 180 kilos. per hour, against 225 kilos. of coal. The price of residuals stood at 40 francs and coal at 32 francs per ton, which represented a saving of about 3 francs per hour. The result of the experiments was so satisfactory that it was anticipated that practically all the steamers plying on the Danube will adopt liquid fuel.

In other marine directions oil is coming extensively into use as fuel.

Another instance is the new American ferry steamer *Ramona,* which uses crude oil between San Diego and Coronado. The vessel is built almost entirely of Oregon pine, and is provided with sidewheels and double ends. She has a length over all, 130 ft.; length between perpendiculars, 118 ft.; breadth of hull, 29 ft.; breadth extremes, 49 ft.; depth of main deck, 13 ft. 9 ins.; draught of water, 6 ft. 3 ins.

A number of improvements were introduced into the system which was first installed on the Shell liner *Trocas.* The system is known as the Flannery-Boyd (fig. 28), in conjunction with which Rusden and Eeles' burner is used. This burner, which is simple in construction, and which has already been described and illustrated, is of the same type as those which have been used in Russia for several years. The Flannery-Boyd system has been provided to overcome the difficulties encountered in converting old steamers for liquid fuel burning. The oil is carried in all the ballast tanks, ordinary coal bunkers not being suitable, the riveting and plating not being oil-tight. These tanks include the double bottom, ballast tanks under the engines and boilers, the forward ballast tank adjacent to the fore peak and the fore and aft cofferdams; the fore and aft peaks are also brought into requisition. But the ballast tanks always contain a certain amount of water, owing to the difficulty of draining them. This water becomes mixed with the liquid fuel, and is liable to cause dangerous explosions at the burners, frequently extinguishing the fires. This difficulty has also been met in the Flannery-Boyd system, and is effected in the following manner. Two liquid fuel settling-tanks of large size are placed in the 'tween decks amidships, immediately adjacent to the boiler-room bulkhead. These tanks are fitted with the necessary heating coils, drainage arrangements, thermometers, and other fittings to enable the liquid fuel to be heated to a sufficient temperature to

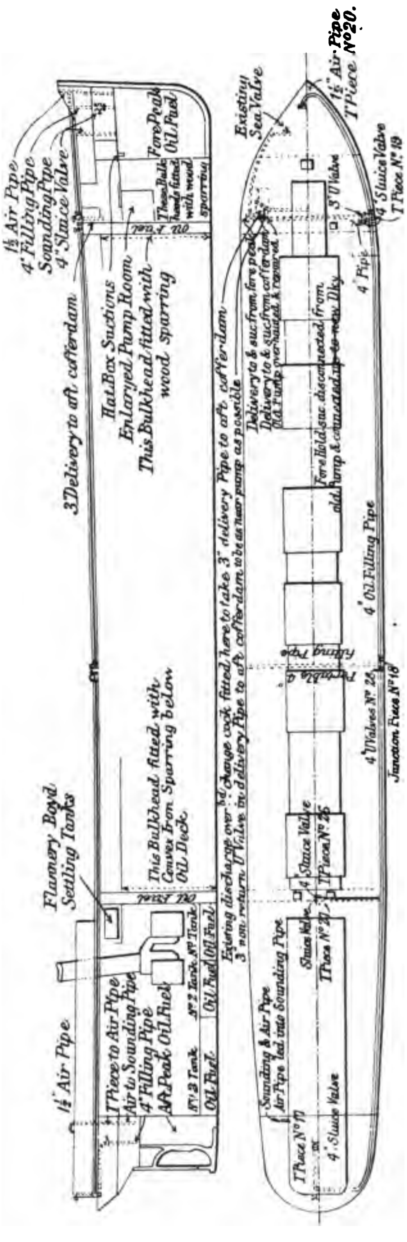


FIG. 28.—Sketch showing storage of oil fuel on Flannery-Boyd system.

allow of the water being freely separated. This latter settles at the bottom of the tank, and can then be drained off. Each of these tanks is large enough to hold half a day's supply of liquid fuel, so that, while the latter is being drawn from one tank, the water is being separated from the oil in the other. This system can be applied to any steamer, as there is usually a certain amount of water mixed with the oil fuel.

It may be mentioned that the *Trocas*, fitted with three furnaces with two burners each, was changed to a coal-burning steamer in 23 minutes, all the three boilers being changed. This alteration was made without the engines being stopped, the speed being only slightly reduced.

CHAPTER VIII.

OIL FUEL FOR NAVAL PURPOSES.

CONSIDERING how vital a matter the supply of fuel to the vessels of the Royal Navy is, it is not surprising that so little advance has been made in the adoption of oil fuel in place of coal. Although nearly forty years have passed since the first experiments were conducted on behalf of the Admiralty, they are still engaged in preliminary trials for proving its efficiency and suitability to warships and other vessels of the fleet. Apart from the usual conservatism of the British people, oil fuel has not offered those advantages which a nation richly endowed with coal could take practical account of, for the reason—and a very vital one it is—that the supply was, geographically, out of reach. This question of supply is naturally of far greater consequence to the Navy than to the merchant service. A shortage or cutting off of supply, if any political crisis should arrive wherein we were called upon to defend our shores and our commerce, would mean national disaster, if not national ruin; therefore, the supply of oil fuel must be absolutely assured and uninterrupted. Until, therefore, the now famous Texas fields were brought in, the question, from the Admiralty's point of view, had to remain in abeyance; but recently the adoption of oil fuel in the Navy has come to the front again, and the results of the official experiments will no doubt be definite and decisive one way or the other. Several aspects of the case certainly compel the Admiralty to look into the subject carefully and exhaustively. One of the advantages of oil over coal for warships is that a larger amount of heating power can be stored into the space available for fuel, which means that the radius of action is extended, a feature of considerable importance in the event of a prolonged absence from land, as well as from a strategical point of view. Speed is also augmented by the use of oil; smokelessness is another qualification, while the space required for storage may be utilised for fighting power. If these advantages are acquired by our adversaries, and we remain in the old rut, then these additional facilities may turn the day against us. This matter must be looked at from a purely national standpoint, and not from one of pounds, shillings, and pence.

In the experiments carried out by the British Admiralty in 1866, the results were not by any means conclusive or satisfactory, in so far that they did not lead the Admiralty to come to any decision, except that the price of the oil prohibited the adoption of the new fuel. The average quantity of water evaporated during the trials was 13·2 lbs. per pound of oil. The conditions of combustion appear to have been very imperfect, the tubes showing a very foul condition at the end of the day's experiments. A mixture of oil seems also to have been resorted to, with what idea it is somewhat difficult to see. When burnt alone, Burslem oil evaporated 18·38 lbs. of water to the pound of oil; shale oil, 17·92 lbs.; and Torbaine Hill mineral oil, 18·38 lbs. The price paid for the oils used is given at from £10 to £23 per ton.

All the great powers have given serious attention to this matter—America, Germany, Russia, Italy—and have, to a certain extent, adopted the use of oil fuel in their navies.

As Sir Fortescue Flannery, M.P., reminded the members of the Institution of Naval Architects some time ago, the problem that confronts every designer of a warship is the combination of the greatest speed, armament and ammunition supply, protection, and range of action, in the smallest and least expensive hull, and any reduction of weight and storage room necessary to any of these qualities is a saving which acts and reacts favourably upon the problem in a manner familiar to us all. The practical figures of comparison between coal and oil fuel realised in recent practice are that two tons' weight of oil are equivalent to three tons' weight of coal, and 36 cubic feet of oil are equivalent to 67 cubic feet of coal as usually stored in ships' bunkers; that is to say, if the change of fuel be effected on an existing war-vessel or applied to any design, without changing any of the data other than those affecting the range of action, the latter is increased by 50 per cent. upon the bunker weight allotted, and nearly 90 per cent. upon the bunker space allotted.

The coal protection for cruisers, also said the same authority, whatever its real advantages—a matter upon which different opinions exist—would disappear with the use of liquid fuel, because it would be for the most part stored below the water-line, if not wholly in the double bottom. The double bottom and other spaces, hitherto quite useless, except for water storage, would be capable of storing liquid fuel, and the space now occupied by coal bunkers would be available for other uses. The writer then touched on the reduction in staff that would be possible on the adoption of liquid fuel, as well as the advantages of rebunkering at sea, which would be made easy to a war-ship even in mid-ocean in ordinary weather, 300 tons an hour being quite a common rate of delivery in the discharge of a tank steamer's cargo.

The evaporative duty required from the boilers of destroyers is greater than that required from the boilers of any other type; and whilst it is possible to burn enough liquid fuel to produce the required duty in boilers hitherto using coal at natural draught, or even coal at moderate forced draught, difficulty has been found in burning enough oil fuel in boilers of the destroyer type to produce the same duty as that realised under coal at great air pressure. The question of economy of fuel in destroyers when at full power is of comparatively little importance, but the production of the maximum power is essential, and further experiments now in process will probably solve the difficulty, as it has been solved in locomotive practice on the Great Eastern Railway by the skill and enterprise of Mr James Holden (see fig. 29).

Messrs Yarrow obtained some highly encouraging results in two torpedo-boats built by them for the Dutch Government. The air pressure for draught in the furnace was 1 inch on the water-gauge; the engine stop-valve was kept full open. The following were the observed results: the boiler pressure was 150 lbs. to the square inch; the

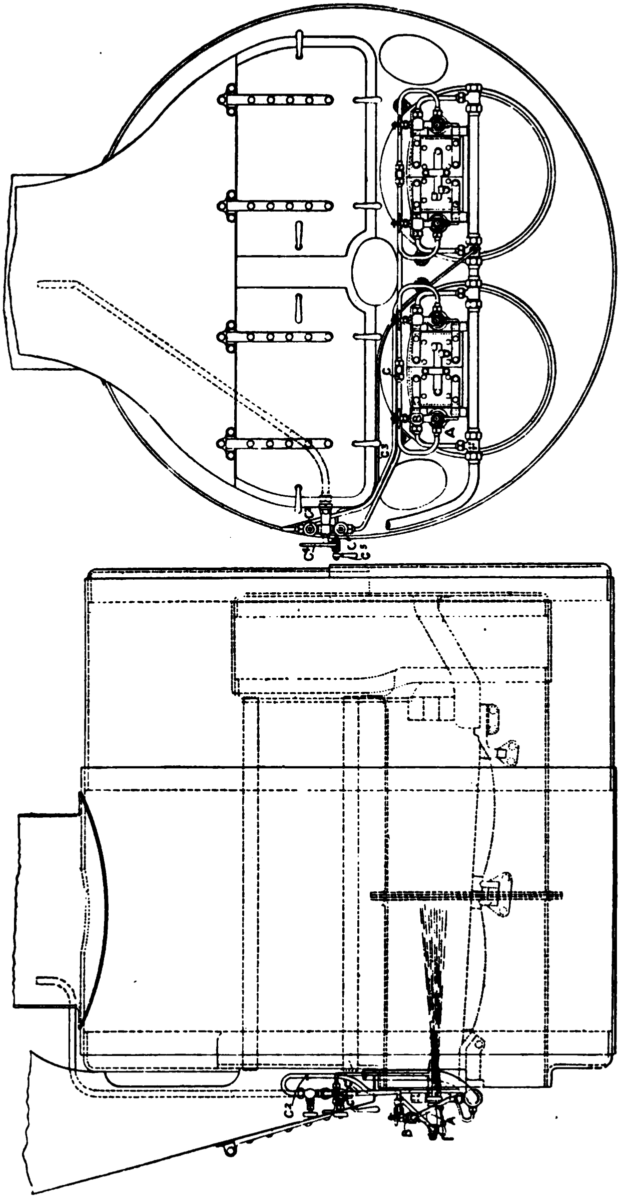


FIG. 29.—Arrangement of Holden's burner fitted to marine boiler.

pressure in the first receiver was 54 lbs., and in the second receiver 5·5 lbs.; the vacuum was 23½ ins.; and the revolutions 340 per minute. The speed was 24½ knots. The oil fuel was then started, and as much oil was burnt as was possible without making smoke. The coal burnt was at the same rate as before. The results were then as follows: boiler pressure, 180 lbs. per square inch; first receiver pressure, 64 lbs., and second receiver pressure, 9 lbs. The vacuum was 23¼ ins.; and the revolutions 365 per minute. The resultant speed was 26½ knots.

Thus, by turning on the oil feed the speed was increased by just two knots. Moreover, this increase was obtained almost instantaneously, or, at any rate, within a few seconds of the oil being turned on. Borneo oil was used, and the supply for the two boilers was at the rate of 700 lbs. per hour. The coal burnt per hour was at the rate of 2800 lbs., both when coal alone was used, and when it was burnt in combination with oil. The oil tank, fitted, holds a supply sufficient for a run of an hour and a half under the above conditions of working; as will be seen, it is placed on deck, so that, if it should be pierced by shot and the oil should escape, it would simply run into the sea.

Messrs Thornycroft have recently made experiments, and have obtained the high evaporative duty of 18·95 lbs. of water per pound of oil fuel.

The extra rapidity of raising steam with liquid fuel is undoubted, and this is a feature upon which much stress has been laid in recent naval debates. So far as experience has shown, there is no deterioration of liquid fuel, however long it is stored before use.

Among the early apparatus employed in the French navy for burning liquid fuel was that of M. Ferrari, of Genoa. This system was composed of longitudinal trays containing wicks separated by screens so arranged as to distribute the air; a tube pierced with holes placed beneath each wick distributed the oil throughout its whole length. Two series of trials were made at Toulon with this apparatus, on the *Amalia* and on a torpedo-boat. The object in this case was only moderate firing, and on a trial in dock the consumption was stated to be 2·12 lbs. of oil per horsepower per hour, and at sea 1·79 lbs., compared with the coal consumption of 3·22 lbs. The results of the trials on the torpedo-boat were, however, very unsatisfactory.

The apparatus which has been used in the French navy is chiefly the Guyot burner, which was tried on board the *Baffle* and a torpedo-boat. In this burner the steam jet is regulated by the movement of the central spindle, which also forms the oil supply. Although it is easier, says M. Bertin, to regulate the steam in this manner, great care is required in order that the spindle regulating the steam supply should remain perfectly central. It is also important that the spindles should not be too long, and that they never project beyond the steam jet.

On the torpedo-boat 11·56 to 11·58 lbs. of water were evaporated per pound of petroleum.

In early trials in France in 1887, 1·2 lbs. of steam were required for each pound of petroleum pulverised. On the *Baffle*, which has already been referred to, the consumption was ·75 to 1 lb., and on the torpedo-boat No. 22 also 1·2 lbs. In the trials made by M. Guyot on his boiler in 1895 the consumption is said not to have exceeded ·63 lb., and even dropped as low as ·25 lb., of steam per pound of oil. In Italy similar results, varying from ·5 to ·25 lb., were obtained, and on a Schichau torpedo-boat the figure of 1·02 lb. of steam is said to have been reached. It may be taken for granted that on an average not more than half a pound of steam is required for vaporising a pound of petroleum. But, of course, on sea the fresh water has to be obtained by distillation. The use of an air-compressor for supplying air in place of steam was, however, unfavourably reported on by a commission which inquired into the subject.

In discussing the question of evaporation, M. Bertin states that a pound of Russian mazout develops 20,000 thermal units, compared with 16,400 thermal units of coal. These figures, however, appear to be somewhat high, although the comparison only makes oil 1·22 times better than coal. The experiments of M. D'Allest, carried out in 1887, showed an evaporation of 11·33 lbs. per pound of oil used, and in 1890, in the navy, on the torpedo-boat already referred to, 11·36 and even 13·25 lbs. of water were evaporated. M. Guyot, in his boiler, evaporated 12·5, 12, and 11·3 lbs. in a closed stokehold and under an air pressure of ·31, ·67, and 1·8 in. respectively. Thus it appears to be equally easy to evaporate 12 lbs. of water with oil as 9 lbs. with a corresponding amount of coal.

Col. Nabor Soliani, of the Italian navy, who was one of the pioneers of the introduction of liquid fuel, found from trials on a torpedo-boat that the superiority of 1·33 might be considerably increased. The consumption on the torpedo-boat with coal amounted to 2·13 lbs. per indicated horse-power, while with liquid fuel it was only 1·25 lbs.

M. Bertin also deals with an aspect of the subject which is not paid sufficient attention to, namely, mixed firing. The main advantage of this mixed firing lies, he remarks, in being able to obtain at will a large increase in the power of the boilers, as the combustion of the petroleum does not in any way prejudicially affect that of coal. This mixed firing is also worth consideration. It may prove the introductory stage to a wider use of liquid fuel, in that the supply at the present time is not sufficient to take the place of any considerable quantity of coal.

M. Bertin's experiences and conclusions may be given in his own words. In the first place, he says, it must be noted that the introduction of jets of petroleum alters the condition and efficiency of combustion by more completely mixing the gases and burning any excess of air. It is therefore not correct to consider the evaporative power of coal as identical when passing from ordinary to mixed firing. Admitting this as a principle, and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation due to the better mixing of the gases is credited to the petroleum.

For a given boiler, if

a be the quantity of water evaporated per pound of coal under ordinary conditions, and
b the quantity per pound under mixed firing,
p the quantity of petroleum burnt while consuming c lbs. of coal, and
x the quantity of water evaporated per pound of coal under mixed firing—

then, assuming a to be constant, the steam produced by the mixture of fuel, $p+c$, is equal to

$$px+ca;$$

therefore, for 1 lb. of the mixture we have

$$\frac{px+ca}{p+c}=b,$$

which gives

$$x = \frac{b(p+c) - ca}{p} = b + \frac{b-a}{\frac{p}{c}}.$$

If we call R the ratio of the evaporative efficiency of petroleum to that of coal, we have

$$R = \frac{x}{a} = \frac{b}{a} + \frac{\frac{b}{a} - 1}{\frac{p}{c}}.$$

There have only been a few evaporative trials made with coal alone and with mixed firing on the same boiler, and very few results have been published. On the *Furieux*, after a trial with coal alone, when 18·8 lbs. of coal were burnt per square foot of grate per hour, two trials were made of mixed fuel with different proportions of petroleum, when 21·3 and 21·7 lbs. of mixed fuel were burnt. The results of these trials, which were carried out under similar conditions, are as follows:—

$\frac{p}{c}$	a	x	$\frac{x}{a}$
	lbs.	lbs.	
0·00	9·05	...	...
0·45	9·05	11·34	1·25
0·64	9·05	14·12	1·56

In the last trial, the efficiency for petroleum when burnt in conjunction with coal is higher than when burnt alone. This ought to be the case under favourable conditions with mixed firing, but it is not always so. On a trial at Cherbourg, with mixed firing and Godard boiler, transformed for mixed combustion, with a high rate of forced draught and petroleum jets not properly arranged in the furnace, the efficiency b was inferior to that of a for coal alone. Although actual evaporative trials are scarce, combined engine and boiler trials, giving the consumption per horse-power with mixed firing or with coal alone, are, on the other hand, plentiful. These trials may serve as bases of comparison, always assuming that the calorific value of the coal remains constant.

If C be the consumption of coal per indicated horse-power when burnt alone, and c and p the consumption of coal and petroleum per horse-power when mixed, the quantity of petroleum p, which will produce one horse-power per hour, will be $C-c$, and as the calorific efficiency is inversely proportional to the amount of coal necessary to do a given amount of work, we have

$$R=\frac{C-c}{p}.$$

This formula only holds if the two trials, alone and mixed firing, were carried on at not too high a rate of forced draught. Generally, a high rate of forced draught is not favourable to the use of petroleum, and the ratio of p to c should be decreased as the rate of combustion increases, if the efficiency R is to be greater than 1, that is to say, if mixed combustion is to show a gain over the combustion of coal alone. There must exist for each rate of forcing a ratio between p and c which corresponds to the minimum value of the total consumption per horse-power, $p+c$, and another ratio corresponding to the maximum horse-power that can be developed. The number of complete trials that have been made is not sufficient to determine definitely the laws relating to mixed firing; the following table, which is a *résumé* of the trials made on a locomotive boiler on torpedo-boat No. 109, may be consulted with interest:—

	1st Series.	2nd Series.	3rd Series.
Air pressure—ins. of water . .	0·6, 0·51, 0·47	1·0, 1·0, 1·14	1·97
Coal alone—lbs. per h.p. hour, c .	2·99, 2·99, 2·99	3·02, 3·02, 3·02	3·37
Coal—lbs. per h.p. hour, c .	2·19, 2·04, 1·30	1·59, 1·61, 1·46	2·72
Petroleum—lbs. per h.p. hour, p .	0·85, 0·87, 1·10	0·90, 1·06, 1·46	0·97
Total—lbs. per h.p. hour, $p+c$	3·04, 2·91, 2·40	2·49, 2·67, 2·92	3·69
$R=\frac{C-c}{p}$ . . .	0·94, 1·09, 1·53	1·58, 1·33, 1·07	0·67

The above table shows that good results may be hoped for at natural draught, or at very moderate rates of forcing, when burning slightly less petroleum than coal. Thus, at natural draught, when burning 16·4 lbs. of coal per square foot of grate per hour, with a combustion of 12·3 lbs. of mazout with an efficiency of 1·5, the same would be developed as when burning 34·8 lbs. of coal. Under these conditions, mixed firing may replace forced draught, over which it has many advantages.

The most recent and probably the most exhaustive naval tests which have been made, were those conducted in 1902 by the United States Navy Board under the direction of Rear-Admiral George Melville, engineer-in-chief of the U.S. Navy. The conclusions which were arrived at during these trials are sufficiently important to find a place in this book, and will therefore be quoted at some length, not only because they form the only recent record of naval practice, but because they bring out certain important points connected with the use of liquid fuel on warships. The results of the steaming tests will also be given, with descriptions of the burners employed.

The numerous experiments, says Admiral Melville, that have been made by several naval powers during the past forty years in the attempt to use oil as a fuel, show how important this question is regarded by military experts. It is now plain why success was not attained. There was too much effort exerted to burn oil in the same manner as coal. It is now realised that the oil should be atomised (it is impossible to completely gasify it) before ignition, and that the length of the furnace, the volume of the combustion chamber, and the calorimetric area are factors which must be considered. In fact, it is highly probable that it may be found advisable to design a special boiler for burning oil.

The more the liquid-fuel question is investigated, the more intricate seems the problem of successfully installing an oil-fuel appliance on board a battleship. It ought to be successfully used on the torpedo-boats, as well as upon auxiliary naval vessels that steam between regular ports. For the army transport service it might prove very desirable, since a supply of oil could be maintained at the several calling ports. In regard to the installation on the large-powered battleships and armoured cruisers, there are three distinct features which must be considered, viz. the mechanical, commercial, and the structural. Regarded from two of these view-points, it seems as if it would be some time before "coaling ship" ceases to be an evolution upon the war vessel. While both the naval and mercantile vessels traverse the ocean, there is a wide difference in their construction as well as in the nature of the duty performed, and this must be taken into account in designing the motive plant.

The experiments conducted by the Liquid Fuel Board have shown that it is now possible to force the combustion of oil, and that the greatest evaporation per square foot of heating surface secured with coal can be greatly exceeded by an oil-fuel installation of modern design, where provision has been made for atomising the combustible and heating the air and oil.

It may be affirmed that the efficiency of the burner is simply proportionate to its power to atomise the oil and then to turn these minute particles of oil into a mixture of combustible gas and fine particles of carbon, so that complete combustion, as well as ability to force the consumption of the oil, can be secured. There are many burners which can atomise the oil quite satisfactorily, and, as constant and progressive improvement is being made in this direction, the engineering and mechanical problem is nearing solution. The heating of the oil, as well as the heating of the air required for combustion, must be provided for, and extended experiments should be made to determine the simplest and the cheapest methods of attaining these objects.

The commercial feature relates to the question of cost and supply. It may be regarded as a certainty that, except where unusual conditions prevail, the cost of oil for marine purposes will generally be greater than that of coal. The cost is even now less for vessels departing from the Gulf and California seaports, but the rule will hold elsewhere. While the question of cost should be of secondary importance in military matters, it must be taken into consideration in industrial matters. It is the expense of transportation that now prevents the oil from being a cheap combustible for marine purposes, but this disadvantage ought to be soon removed. While it may be put on the tank steamer very cheaply at ports like Point Sabine, its commercial value will be determined by the cost of delivery at commercial and maritime centres. This feature of the problem is beyond the ability of the Navy to control, but it must be regarded as an important phase of the subject.

It is undoubtedly a fact that the transportation charges per mile for oil at the present time are excessive compared with the freightage for coal, and this incongruity of expense account against oil cannot continue much longer.

As regards the question of supply, it may be more expensive if not difficult to transport and to store oil than coal. The fumes of all petroleum compounds have great searching qualities, and therefore extreme precaution will have to be taken to guard the storage tanks. If it be true that for military purposes it is best in time of war to keep all reserve fuel afloat, then liquid fuel is at a disadvantage in this respect. The mining and railroad companies have invested so heavily in the coal industry, and the transportation facilities have been so perfected, that it is now possible to quickly deliver a cargo of coal at any point in the world. There has been, likewise, a development in the method of loading and unloading cargoes of coal. Since it will require progressive development to perfect the transportation and the storage of oil, and as the world's supply is still an unknown quantity, it will be some time before there may be a reserve supply of oil at the principal seaports.

It must also be remembered, Admiral Melville says, when considering the problem of supply, that the naval vessel must be kept in readiness for orders to proceed at any time to any port within her steaming radius. The merchant vessel steams between regular seaports, where it would not be difficult to induce merchants to keep a supply of oil as soon as there is a regular and constant demand for it. The question of supply for battleships and cruisers may therefore not only be a commercial affair, but prove to be a military problem, since the oil requirements of naval vessels for service conditions might only be met by the Government establishing oil-fuel stations. The military aspect of the question may prove to be a serious problem, since it not only necessitates heavy expenditures, but it may involve the greater question as to the wisdom of maintaining a complete chain of fuel stations between country and colony.

The structural feature of the battleship, he proceeds, may prove a serious detriment to the installation of an oil-fuel appliance. The problem of storing oil on board warships which possess protective decks is much more complex than the problem of its storage in vessels of the merchant marine. Everything on board the battleship is subordinated to making the vessel a gun platform. There are many more compartments in the war vessel than in the merchant ship.

In all probability the great bulk of the oil in the warship would have to be kept in the double bottoms. As the petroleum vapours are quite heavy, it may be a difficult matter to free these compartments of explosive gases, especially when the compartments are partly empty. By reason of the great number of electrical appliances in use on board the warship, thousands of sparks are likely to be caused, any one of which might cause an explosion and set the oil fuel on fire. Our limited experience with submarine boats may give us an object lesson as to the liability of hydrocarbon gases to explode.

In view of the results already secured by the Liquid Fuel Board, he has no hesitation in recommending that an installation should be effected without delay on at least a third of the torpedo-boats and destroyers.

Then comes the report drawn up by Lieut. W. Winchell on the voyage of S.S. *Mariposa*, of the Oceanic Steamship Company, using oil fuel on the round trip between San Francisco and Tahiti.

The *Mariposa* is a single-screw iron steamer, built at the yard of William Cramp & Sons, Philadelphia, Pa., in 1883. She has just had new engines and boilers installed by the Risdon Iron Works, San Francisco, Cal. The oil-burning plant has just been installed by the same company.

This vessel has been employed in the Pacific trade, and is now running to Tahiti from San Francisco, making the round trip voyage of 7320 knots each month.

DESCRIPTION OF THE "MARIPOSA."

Gross tonnage		3160
Length between perpendiculars	feet	314
Beam	,,	41
Mean draught	,,	22
Depth of hold	,,	$17\frac{3}{12}$

There is a single bottom with four watertight athwartship bulkheads, and two masts, square rigged on the foremast.

The total crew was formerly 81, but since the change from coal to oil burning 16 men have been taken out of the engineer's force, reducing the crew to 65 men, and making the engineer's force for oil burning 20 men, as follows: 1 chief engineer, 3 assistant engineers, 3 oilers, 1 electrician, 1 attendant for ice machine, 1 attendant for air compressor, 3 water tenders, 6 firemen, 1 storekeeper—total, 20.

There is one triple-expansion engine of the inverted direct-acting type, with cylinders 29 ins., 47 ins., and 78 ins., by 51-in. stroke, designed for 2500 indicated horsepower, fitted with piston valves on the high-pressure and intermediate pressure, and slide valve on the low-pressure cylinders, all driven by link motion. The condenser is part of the back framing. The cylinders are not jacketed.

There are three cylindrical tank boilers placed fore and aft in the line of the ship—two are double-ended, 15 ft. 3 ins. diameter by 17 ft. 3 ins. long, and one single-ended, 14 ft. diameter by 9 ft. 9 ins. long, the latter placed amidships forward of and worked from the forward fire-room. Each double-ended boiler has six corrugated furnaces; the double-ended boilers have a common combustion chamber for opposite furnaces, while the single-ended one has a common combustion chamber for its three furnaces. The combustion chambers of the double-ended boilers have a brick bridge wall, and the back sheet of the single-ended one is covered with fire-brick. The decision to use oil in place of coal was not made until the changes in engines and boilers were well under way, and it was decided to put the ship on the route to Tahiti. The steam pressure is 180 lbs. There is one auxiliary boiler, two-furnace return-tube type, in upper fire-room hatch, and fitted to burn coal only.

The oil-tanks were constructed out of the old coal-bunker space forward of the boilers, and as the steamer is intended to carry oil for the round trip of about 7320 miles, some additional space had to be taken from the fore hold.

The total capacity of the tanks was 6338 barrels of oil, or about 905·43 tons. The oil is heated by a steam coil to not more than 150° F., and thence led by a pipe to the burners. The air from the compressors, under a pressure limited to 40 lbs., discharges into the top of the heater tank on its way to the burners, so that the oil and the air go to the burners under the same pressure.

The air compressor was placed in a pocket off the upper engine-room platform, and consists of duplicate steam and air cylinders connected to a crank shaft carrying a fly-wheel turning between the cylinders. Either set is large enough to supply all the air necessary. The air compressor is horizontal, double-acting, duplex. Air cylinders 22 ins., steam cylinders 12 ins., diameter, by 18-in. stroke for all cylinders. Capacity equals 1000 cubic feet of free air per minute compressed up to 30 lbs. at 120 revolutions per minute. Air is used at the heat of compression, or as heated by the air heater.

The atomiser was the joint invention of Messrs Grundell and Tucker, San Francisco.

A part of each furnace front is a hollow iron casting through which the air passes on its way to the atomisers and becomes heated. The chamber surrounding the burner is lined with a crucible lead lining; a by-pass to the burners is provided for use in case of accident to the heater. The lower part of the furnace front is a door on hinges that can be fastened open at any desired degree to give air for combustion. There are also two louvres in the door for the same purpose. Near the front of the furnace, inside the door, is placed a brick wall made to deflect upwards the inward current of air to meet the rose-shaped flame from the burners. There is ample space over the brick wall for a man to enter the furnace through the ash-pit door. The double furnace combustion chambers have a brick bridge wall reaching above the top of the furnaces, and in the single-ended boiler the common combustion chamber has the back sheet covered with fire-brick to protect it.

Before the actual voyage was commenced, a couple of trial trips were made, and the results of these are given. The oil used on both runs was from the Kern River district, near Bakersfield, Cal.

The following data were observed:—

Steam pressure	lbs.	160–170
Revolutions of engine		74–77
Revolutions of air compressor		60
Pressure of air	lbs.	20
Temperature of oil entering heater	degrees F.	80
Temperature of oil leaving heater	,,	120–130
Temperature at base of stack	,,	750

The chemist at the New York yard submitted the following report upon the sample of the Kern River district oil sent him for analysis:—

"The sample is practically free from low boiling naphtha, as on distillation only a small percentage passed over below 150° C., and less than 10 per cent. below 225° C. A boiling point above 360° C. was reached before the second 10 per cent. was collected.

"It shows on ultimate analysis the following composition:—

	Per Cent.
Carbon	84·43
Hydrogen	10·99
Nitrogen	·65
Sulphur	·59
Oxygen	3·34

"This gives a calorific value, by Dulong's formula, of 18,806 B.T.U. The specific gravity at 60° F. is 0·962, Flash point, 228° F. Fire point, 258° F. Vaporisation point, 178° F. Loss for six hours at 212° F., 12·01 per cent."

The *Mariposa* left San Francisco on July 15, 1902. On arrival at Tahiti the most careful inspection was made of the boilers, but no bad effect of the flame was found to have occurred. No leaks or defects developed anywhere, and there was no difficulty in feeding them.

At Tahiti the tubes were swept by tube scrapers, and back connections, uptakes, ash-pans, and furnaces were cleaned. All the refuse from these various places barely filled two ash buckets. This refuse, mainly soot, was the result not only of the twelve days' run to Tahiti, but also of the three preliminary trials by the contractors. The first one, a four-hour trial of engines and boilers, was made with Comax coal, and the other two were free runs at sea, of about eight hours' duration each, burning oil. The tubes had never been cleaned previous to arrival at Tahiti. It is the intention hereafter to make the round trip of twenty-four days' steaming without sweeping tubes.

There are no precautions other than those usually taken on board ship to guard against fire or explosion. All spaces to which oil has access are well ventilated by both inlet and outlet ducts. The oil is a thick, dark fluid, like molasses, and in the open air burns slowly, giving off much smoke; but it gives off volatile gases which form explosive mixtures with air, tanks empty or nearly so being more dangerous than full ones in this respect. The ship is electrically lighted, but in addition an open hand lamp is burning in the fire-room all the time to light the burners; the firemen smoke on watch, and the oil is treated no more tenderly than if it were coal. On the run back, the cargo of copra was stored all about the expansion trunk, which projects up 4½ feet between decks, completely covering the tanks and making them inaccessible for examination.

Of the 6 firemen, 3 were relieved from watch the second day out, leaving but 1 man on a watch to fire 12 furnaces in two different fire-rooms separated by the length of the double-ended boilers. The water tender did not touch the burners except in emergency, his duty being to tend water, fill settling tanks and record height of oil in them, record temperatures of oil at settling tank and in heater of fire-room, and of superheated air, take reading of lower pyrometer where the two uptakes meet, and run oil pump supplying oil to the settling tanks and small oil pump supplying oil to the oil heater.

As a coal-burner the *Mariposa* formerly had the following engineer force: 1 chief engineer, 3 assistant engineers, 3 oilers, 12 firemen, 12 coal passers, 3 water tenders, 1 messenger, 1 storekeeper—total, 36.

A reduction of 16 men in the fire-room force is effected by oil-burning. At sea she needs now but 3 firemen, but carried 6. This would reduce the force by 19 men.

The temperatures of the fire-rooms seem to be about what one would expect in coal-burning, but the temperature of the uptake and smoke-pipe gases runs high, the maximum being 925°, which shows an undue loss of heat here. The temperature of the oil in the settling tanks ranged between 68° and 100° F. on the trip out, and between 90° and 108° F. on the trip back.

The oil auxiliaries comprise 1 large oil pump, 2 small oil pumps, 2 oil heaters, 1 air compressor, and 4 strainers.

There is a steam-pipe connection to blow out the oil strainers, and another one to blow out the oil burners when clogged.

On August 3 the air compressor needed overhauling, and steam atomising was kept up for two and one-half hours until the compressor was again working. During this time the evaporator supplied enough feed water to use 20 burners; the engines were not stopped while shifting from steam to air atomising, and averaged 67·8 turns for the two and one-half hours. They had before been making 70 turns. Also during the four days in port at Tahiti the forward main single-end 3-furnace boiler was used, atomising with steam. Generally 2 burners in the middle furnace gave ample steam to run the following auxiliaries, all exhausting into the atmosphere, the boiler being fed with fresh water from the dock: Ice machine, dynamo, flushing pump, feed injector, 2 cargo winches, small portable steam pump, and steam for cooking, bath-tubs, etc.

At first 2 firemen and a water tender were on watch at a time, each fireman having 1 fire-room of 6 furnaces or 12 burners. The men had but little experience, combustion was poor, much smoke was made, much oil burned, and poor speed attained. To locate the responsibility for bad adjustment of burner valves, but 1 fireman was put on at a time to attend 12 furnaces (24 burners). This made an improvement in the combustion.

Unfortunately, the top of the funnel could not be seen from either fire-room, though the fireman could tell by the appearance of the flame as shown in the sight-hole, or even by the roar of the burner, when the combustion was perfect.

In designing a boiler-room for liquid fuel the ventilators should be so arranged that a view of the top of the smoke pipe can be had from each fire-room.

The work of the fireman would be even easier than it is and better results attained if the oil and air pressures were kept constant, and also the temperature of the oil. The apparatus then, once properly adjusted, would need very little change. To get these results is a mere matter of detail easily arranged. If the temperature of the oil rises it feeds more freely, and a readjustment is necessary, and the same conditions hold with regard to the pressure.

It will be seen (fig. 30) that in addition to the independent oil and air supply valves the burners are fitted with an air plug cock and an oil plug cock connected to one lever, which controls both air and oil supply, enabling the operator to shut them both off at once in emergency. At first when steam went up too high and a burner was shut down this lever was used; but shutting off the air thus gave the air compressor less work, and as its governor is not sensitive, the air pressure increased, making a readjustment of all oil and air supply valves necessary, with consequent smoke. Later on, when it was desirable to shut down a burner, the oil alone was shut off by the independent feed valve on the burner, and the untouched air valve kept the air compressor's work more nearly constant; then when the burner was again required, the oil valve was opened and immediately lighted from the flame of the adjacent burner.

In starting fires with everything cold, steam is raised on the auxiliary boiler, which burns coal, and the air compressor, oil pumps, and oil heater are started. The oil is lighted by inserting oil-soaked rags in the air space surrounding the burner and touching a lamp to them, or an arrangement like a gas-lighter may be used.

Sometimes when the air pressure is too high, or insufficient oil is feeding, the flame flickers and may go out. If the oil is kept feeding under these conditions, on relighting there is a small explosion of the gases in the furnace, with a momentary back-draught through the peep-holes and ash-pans.

When shut down on July 19, for two and one-half hours, for plugging condenser tubes, one burner at each end of each boiler (4 burners in all) furnished steam to run all auxiliaries, including feed pump, bilge pump, air compressor, ice machine, dynamo, and flushing pump, all of which were exhausting into the atmosphere.

In the Grundell-Tucker burner (fig. 30) the oil, heated by a steam coil under boiler pressure throttled down, passes through the inside pipe and is thrown out radially through the series of small holes. The air, first heated by compression up to 20 lbs., is further heated to a temperature of about 350° F. in the air chamber surrounding the burner, and called the air superheater. Air can be used at the temperature at which it leaves the compressor, and was so used on the trip down until July 17, when the superheaters were connected up. This air, under the pressure of about 20 lbs., surrounds the oil pipe in the burner and passes axially along the pipe until near the end, where it is given a whirling motion through small helical passages arranged like the rifling of a gun. It crosses axially, and whirling through the fine oil streams spurting radially from the end of the burner, breaking up the oil into fine spray, the drops of which can be seen before they ignite.

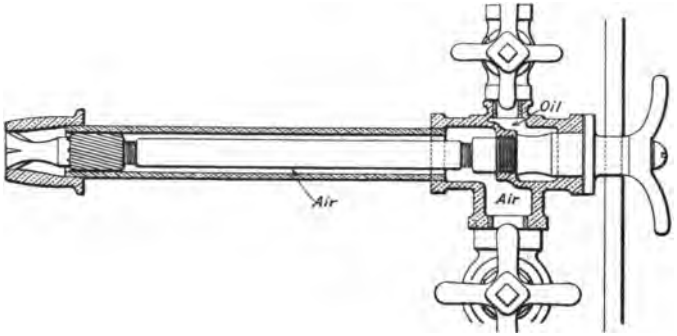


FIG. 30.—Grundell-Tucker burner.

A further air supply (cold) is admitted through the hinged door of the ash-pan, and is directed up across the path of the flame and heated also by a curved fire-brick wall built in the ash-pan close to the front.

The principal difficulties encountered were in the regulation of the supply of oil to the heaters by the pump, and the consequent variation of the temperature of the heated oil, and the freedom of flow through the burners. An automatic submerged float, arranged like a steam trap and fitted in the oil heater to control the throttle of the pump, failed to give good automatic results, and the supply of oil was regulated by hand. If the oil is heated too much (above 150° F.), some of the volatile gases are given off and mingle with the air pressing on top of the oil in the heater, thence passing with the air into the air superheaters and burners, the result being that on one occasion a heater got red-hot from this cause.

Another difficulty was due to the choking of the strainers by foreign matter and impurities in the oil, shutting off the supply of oil, and on one occasion, August 10, putting out all the fires. Just previous to the fires going out, and while the usual air supply was on, and an insufficient amount of oil being fed, a dense white smoke like steam arose from the funnel.

This strainer difficulty will be solved by fitting the strainers in pairs, so that a clean one can always be switched in while the choked one is being cleaned.

Full power was not developed in the two boilers used, as schedule time was easily exceeded with from two to four burners shut off, though it would not appear, from the tabulated results, that the indicated horse-power would equal what can be got by a good system of forced draught. This burner, however, works well with the Howden system of forced draught, as seen on the tank steamer *George Loomis.*

It must be remembered that the tabulated calculations are all based on the indicated horse-power of the main engines only, as it was considered better to use only data actually obtained, and afterwards estimated data, such as indicated horse-power of auxiliaries, could be applied without vitiating the observed data and results. No cards could be taken from any of the auxiliaries, but careful estimates give the following results:—

	I.H.P.
Air compressor, at 60 revolutions per minute	110
Auxiliary feed pump and two oil pumps, one in intermittent use	30
Dynamos	30
Ice machine	7
Circulating pump	5
Flushing pump	2
Baths, steam tables, evaporator, cooking, etc.	11
Total	195

The weight of the oil auxiliaries was as follows:—Air compressor, 9 tons; two settling tanks, 12 tons; two oil heaters, 2 tons; two small oil pumps, ½ ton; one large oil pump, 1¼ tons; fifteen superheaters (air), 3·1 tons; pipes, valves, etc., 8 tons.

It should be remembered that the boilers were originally designed for coal-burning, and that the oil-burning plant was fitted in a hurry. With the air pressure constant, and with oil heated at constant temperature, about 140° F., with oil strainers arranged in pairs, so that one is always efficient, and with experience in firing, the result in economy of oil should have been much better than it was.

The tables given below show the statistical details of the return voyage, when the crew was better acquainted with the new method, and improvements had been made in the oil-fuel apparatus:—

O.S.S. "MARIPOSA," VOYAGE NO. 2, FROM SAN FRANCISCO TO TAHITI, 1902.

Date.	Knots per day.	Knots per hour.	Revolutions per minute.	Oil used per day, in barrels.	Oil used per day, in tons of 2240 lbs.	Oil used per hour, in lbs.	Lbs. of Oil per knot run.	Knots made per ton of Oil.	Distance run per barrel of Oil, in knots.	Slip of Propeller, per cent.
August 21 . .	328	13·3	63·7	255	36·43	3400	248·8	9·00	1·29	7
,, 22 . .	297	12·3	62·6	225	32·14	3000	242·8	9·24	1·32	13·4
,, 23 . .	282	13·3	64	210	30·00	2800	237·4	9·43	1·35	9
,, 24 . .	330	13·6	65·9	235	33·59	3133	227·9	9·82	1·40	8·8
,, 25 . .	310	12·8	62	220	31·43	2933	227·1	9·86	1·41	8·8
,, 26 . .	311	12·8	62	210	30·09	2800	216·1	10·37	1·48	8·5
,, 27 . .	292	12·1	62	220	31·43	2933	241·1	9·29	1·33	13·8
,, 28 . .	305	12·6	62·1	220	31·43	2933	230·8	9·70	1·39	10·3
,, 29 . .	305	12·6	62·2	220	31·43	2933	230·8	9·70	1·39	10·5
,, 30 . .	322	13·3	65	230	32·86	3066	228·6	9·80	1·40	9·5
,, 31 . .	326	13·5	66	240	34·28	3200	235·6	9·51	1·35	9·4
Average, 11 days	309·9	12·96	63·4	226	32·28	3018	233·3	9·60	1·37	9·9
Voyage 1, 11 days	312·7	13·12	65·2	254·8	36·40	3412	260·9	8·585	1·22	13·14

Average temperature of uptake, 548°; average temperature of superheaters, 360°; average temperature of cold oil, 91°.

O.S.S. "MARIPOSA," VOYAGE NO. 2, FROM TAHITI TO SAN FRANCISCO, 1902.

Date.	Knots per day.	Knots per hour.	Revolutions per minute.	Oil used per day, in barrels.	Oil used per day, in tons of 2240 lbs.	Oil used per hour, in lbs.	Lbs. of Oil per knot run.	Knots made per ton of Oil.	Distance run per barrel of Oil, in knots.	Slip of Propeller, per cent.
September 6 . .	292	12·2	62·1	215	30·71	2867	235·6	9·51	1·36	12·6
,, 7 . .	301	12·6	62·6	220	31·43	2933	233·8	9·57	1·37	11·2
,, 8 . .	288	12·1	62·9	220	31·43	2933	244·4	9·16	1·31	15·5
,, 9 . .	298	12·5	63·1	220	31·43	2933	236·2	9·48	1·35	12·6
,, 10 . .	276	12·2	64·7	220	31·43	2933	255·1	8·46	1·25	13·4
,, 11 . .	327	13·7	66·9	245	35	3267	240	9·34	1·33	9·4
,, 12 . .	303	12·7	67·1	250	35·71	3333	264	8·48	1·21	16·5
,, 13 . .	317	13·2	67·3	265	37·44	3533	267·5	8·53	1·20	13
,, 14 . .	307	13·2	67·4	260	37·45	3466	271	8·20	1·18	13
,, 15 . .	324	13·8	69	265	37·94	3533	261·7	8·54	1·22	12
,, 16 . .	321	13·5	69·2	270	38·57	3600	269·1	8·32	1·19	13·9
Average, 11 days	304·9	12·7	65·7	241	34·46	3212	252·6	8·87	1·27	13·01
Voyage 1, 10 days	331·9	13·96	70·6	295·5	42·22	3981·6	284·79	7·841	1·122	12·89

Average temperature of uptake, 546°; average temperature of superheaters, 360°; average temperature of cold oil, 90°.

The Liquid Fuel Navy Board subsequently made a report on the fourteen official experiments which had been conducted under its direction. This report contains some valuable comments, conclusions, and suggestions which will be of interest to all engaged in the use of oil fuel in either of the marine services. The Liquid Fuel Board collected all available data on the subject. An examination proved that a great deal of this was unreliable, and therefore had to be discarded. As this report points out, the naval problem is a complicated one, and an extended series of experiments alone should decide the matter for so important a work.

It will, says the Board, tax the ability of the naval constructor to solve the construction problem involved in installing oil-fuel appliances on board the battleship, since it will not be possible to find such satisfactory storage compartments in the fighting ship as in the freighter.

It is the engineering or mechanical feature of the problem that the Board is concentrating its energies upon. Therefore the Board proposes to try to solve some of the following problems in connection with the subject:—

1. The relative advantages of air and steam as an atomising agent for liquid fuel. The question of supply of fresh water is very important in the Navy, and therefore the use of steam should be obviated, if possible. On the other hand, the air compressors are heavy and take up considerable room. As air compressors, however, are used for many purposes on board ship, it might be possible to have a central plant for all purposes. It is also important to know to what extent it will be necessary to superheat the steam in case it is used as the atomising agent.

2. There is a wide divergence of opinion as to the pressures at which oil, steam, and air should be delivered to the burners. Progressive tests may afford valuable information upon this point.

3. The design of the steam generator. As the experimental boiler now in use by the Liquid Fuel Board (fig. 31) is of the water-tube type, it will be possible to extend the length of the furnace and make other changes which will give important information as to whether or not it would be advisable to design a special form of marine boiler for oil-fuel installation.

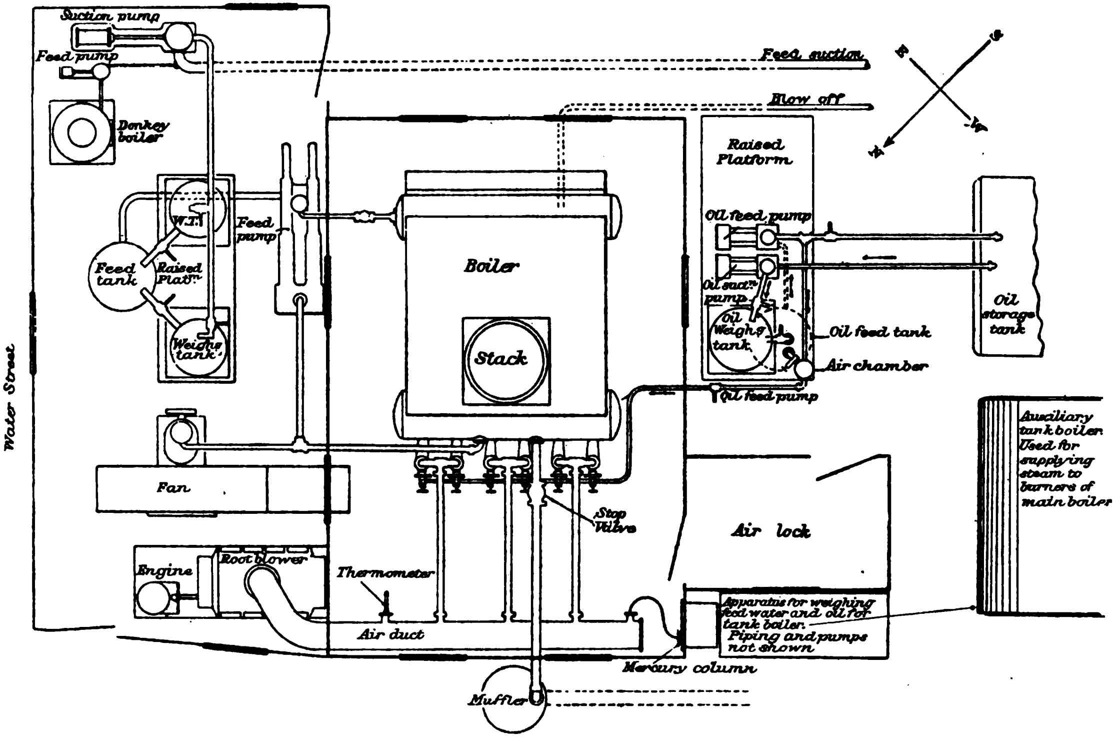


FIG. 31.—Hohenstein experimental boiler plant, used by U.S. Navy Board for liquid fuel tests.

4. The simplest and most economical means of heating the air and the oil. In view of the result of the present experiments and of the information obtained from outside sources, there is no doubt that the air should be heated; and it would seem that, particularly in a water-tube boiler, such heating could be effected in a simple and cheap manner by utilising the heat radiated to the ash-pit.

5. The value or necessity of an air receiver when compressed air is used as the atomising medium. Can the pulsations of the compressor be reduced or minimised by installing such an intermediate receiver between the compressor and the burner?

6. Experiments could be made concerning the baffling of the gases, for the tests already conducted show that the calorimeter area can be somewhat reduced when using oil.

7. The relative value of leading types of burners. Particularly is it necessary to know whether a simple burner should be installed and provision made for heating the air, or whether an appliance should be installed which partly gasifies the oil before ignition. There are on file in this Bureau over 2000 drawings and specifications pertaining to the use of liquid fuel, and it is said that new patents are being issued at the rate of about 30 a week. In view of such widespread interest in the subject, the Board deems it important to test representative types of the various classes of burners.

8. The problem as to whether the oil could be consumed under all conditions without producing smoke. In the naval service this is an important question. As there is also a tendency to compel manufacturers to take means to prevent smoke issuing from the stacks of their plants, the question also concerns the general public.

The burner shown in fig. 32 is an air burner of the Oil City Boiler Works, and was used during the seven general tests that were conducted to show, among other things, whether or not it would be possible to secure a greater evaporative efficiency from the boiler with oil than was secured with coal. Six of these burners, spaced 18 inches apart, were ranged across the front of the furnace, there being a separate opening in the furnace wall for each burner. Considering the burners as arranged in pairs, those of each pair were inclined toward each other at an angle such that their flame impinged near the transverse centre line of the furnace.

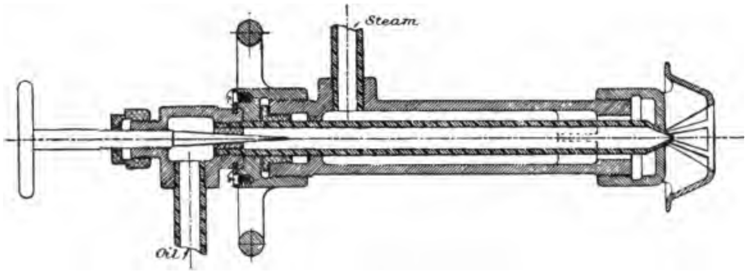


FIG. 32.—Oil City Boiler Works' burner.

The oil used was Beaumont oil, and was of the following analysis:—

Analysis of Beaumont Crude Oil.

	Per Cent.
Carbon (C)	84·60
Hydrogen (H)	10·90
Sulphur (S)	1·63
Oxygen (O)	2·87

The amount of sulphur in different samples of the crude Beaumont oil varies from 2 to 3 per cent.

Calorific value per lb. of combustible	B.T.U.	19,060
Specific gravity		0·924
Flash point	degrees F.	180
Fire point	,,	200

On distillation at atmospheric pressure to 524° F. it was found that the—

	Degrees F.
First 10 per cent. passed over below	428
Second 10 per cent. passed over between	428 and 485
Third 10 per cent. passed over between	485 and 524
Fourth 10 per cent. passed over between	524 and 554

Analysis of Oil used by Liquid Fuel Board, as determined by the Chemist of the Navy Yard, New York.

On distillation at atmospheric pressure to 680° F. it was found that with the oil used during the tests—

	Degrees F.
First 10 per cent. passed over between	216 and 482
Second 10 per cent. passed over between	482 and 523
Third 10 per cent. passed over between	523 and 552
Fourth 10 per cent. passed over between	552 and 680

This oil showed on analysis to be composed of the following constituents:—

	Per Cent.
Carbon (C)	83·26
Hydrogen (H)	12·41
Sulphur (S)	·50
Oxygen (O)	3·83

The sulphur was determined by oxidation with fuming nitric acid in an open capsule.

Specific gravity at 60° F.		0·926
Flash point	degrees F.	216
Fire point	,,	240
Vaporisation point	,,	142
Loss for six hours at 212° F.	per cent.	21·65

The calorific value of the combustible, calculated on the analysis of the United States Chemist by Dulong's formula, was:—

$$\text{British thermal units} = 14{,}500\ \text{C.} + 62{,}100(\text{H} - \text{O}/8) = 19{,}481.$$

These analyses show that nearly all the sulphur was removed from the crude petroleum.

Another burner used by the Board was the Hayes. The construction of this burner is shown in fig. 33, and the manner of its installation in fig. 34. Part of the

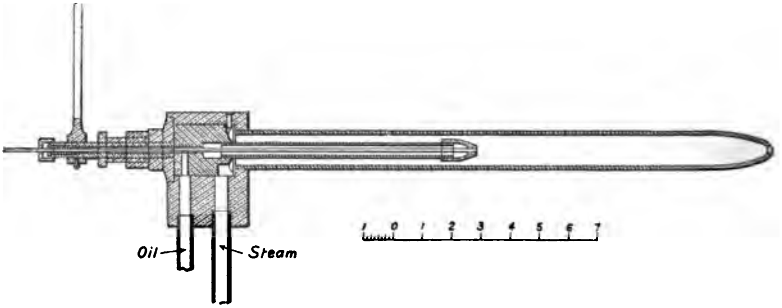


FIG. 33.—The Hayes burner.

air supply is introduced at the sides of the furnace near the back wall. It then passes through heating pipes A A to

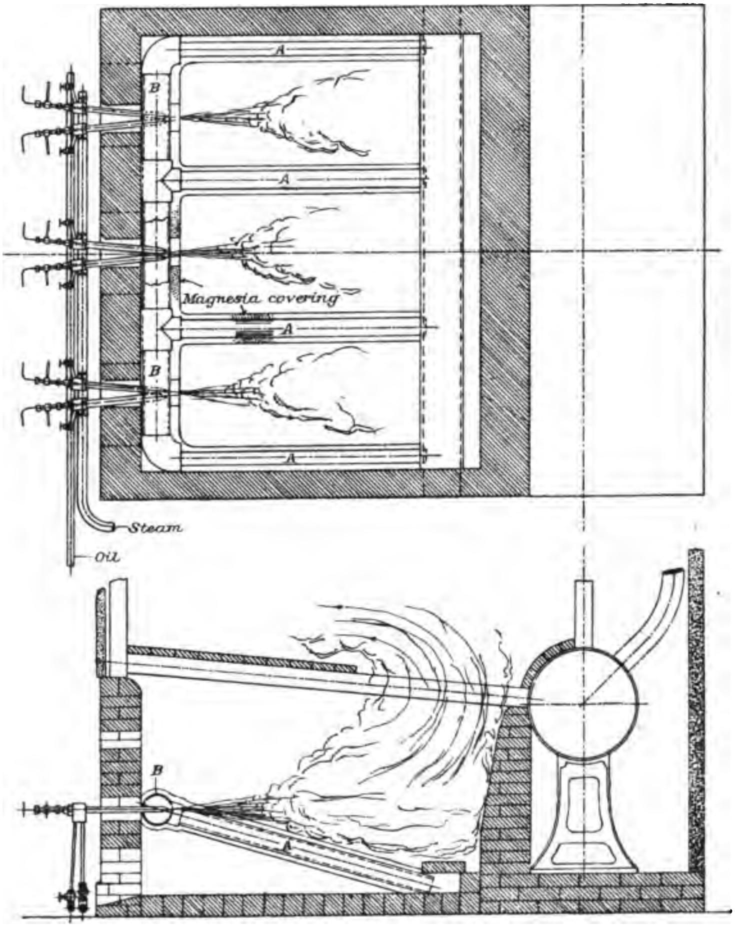


FIG. 34.—Hayes burners and furnace arrangement.

the pipe B, the latter extending across the furnace just inside the front wall.

The burners project diametrically through the pipe B, and it is contended that the hot air in this pipe will cause the oil to be completely gasified before it escapes from the burner orifices. There is no doubt that the heating of the air is a direct benefit. Careful and extended experiments will have to be made to show whether this heating could best be effected as in the Howden system of forced draught, or by a simple arrangement of pipes which receive the direct heat of the furnace. The experience of simply heating the pipes during these tests would rather tend to show that this arrangement would not have much endurance. The edges of the holes in the pipe B were found somewhat burned upon completion of the official test. If such impairment could occur after the pipe had been in actual service about twenty hours, it is probable that very little endurance can be expected of such an installation under forced draught conditions.

On the point of the requisite amount of steam for atomising the oil, the Board made some special experiments. The boiler used was of the cylindrical return-tube type, with two plain cylindrical furnaces. This boiler is piped to furnish steam for the oil burners, and has no other steam pipe leading from it.

The opening from the safety valve was blanked. This boiler is fitted with two oil burners of Oil City Boiler Works' design in each furnace, these burners using air for atomising purposes. After steam was raised one burner in one furnace was found sufficient to keep the steam pressure uniform.

The boiler was put in thorough order at the Navy Yard, New York, and carefully made tight at 100 lbs. pressure. During the oil-burning test great care was taken to keep both the water level and the steam pressures in this boiler uniform. The water used was carefully weighed in a separate weighing apparatus.

The pressure for atomising purposes, as well as the pressure at which the oil was forced to the burner, was increased each day. It was found that the higher the pressure the greater the amount of water that was evaporated. The efficiency was also slightly greater as higher pressures were used. The percentage of steam required for atomising the oil, however, also slightly increased as the pressure rose.

During these tests deflectors were placed in the ashpan openings, so as to cause the air to be drawn up near the burners, thus effecting combustion near the front of the furnace. The average percentage required for atomising purposes was about 4½ per cent. of the entire evaporation.

The F. M. Reed combined air and steam burner was also experimented with, but the results were not satisfactory. The amount of steam consumed in spraying the oil was excessive, being about 1 lb. of steam per pound of oil. The conclusion arrived at was that the combined use of air and steam in burners is undesirable.

There is, continues the report, quite a widespread misconception regarding the part that the steam used for atomising purposes plays in effecting combustion. It is supposed by many that after atomising the oil the steam is decomposed, and that the hydrogen and carbon are again united, thus producing heat and adding to the heat value of the fuel. While it may be true that the presence of steam may change the character and sequence of the chemical reaction, and result in the production of a higher temperature at some part of the flame, such an advantage will be offset by lower temperatures elsewhere between the grate and the base of the stack. All steam that enters the furnace will, if combustion is complete, pass up the stack as steam, also carrying with it a certain quantity of waste heat. The amount of this waste heat will depend upon the amount of steam and its temperature at entrance of the furnace. The quantity of available heat, measured in thermal units, is undoubtedly diminished by the introduction of steam. In an efficient boiler, it is quantity of heat rather than intensity that is wanted. For many manufacturing purposes intensity of heat may be of primary importance, but in a marine steam generator a local intense heat is objectionable on other grounds than those of economy, viz., its liability to cause leaky tubes and seams from the unequal expansion of heating surfaces.

It is believed that expert engineers will be able to make important deductions from the trustworthy data that have been so carefully collected. The tables should be carefully studied in connection with the information secured during the coal tests, and the Board enjoins that the two reports be studied together.

The following facts have undoubtedly been proved:—

(*a*) That oil can be burned in a very uniform manner.

(*b*) That the evaporative efficiency of nearly every kind of oil per pound of combustible is probably the same. While the crude oil may be rich in hydrocarbons, it also contains sulphur, so that, after refining, the distilled oil has probably the same calorific value as the crude product.

(*c*) That a marine steam generator can be forced to even as high a degree with oil as with coal.

(*d*) That up to the present time no ill effects have been shown upon the boiler.

(*e*) That the firemen are disposed to favour oil, and therefore no impediment will be met in this respect.

(*f*) That the air requisite for combustion should be heated if possible before entering the furnace. Such action undoubtedly assists the gasification of the oil product.

(*g*) That the oil should be heated, so that it could be atomised more readily.

(*h*) That when using steam, higher pressures are undoubtedly more advantageous than lower pressures for atomising the oil.

(*i*) That under heavy forced-draught conditions, and particularly when steam is used, the Board has not yet found it possible to prevent smoke from issuing from the stack, although all connected with the tests made special efforts to secure complete combustion. Particularly for naval purposes is it desirable that the smoke nuisance be eradicated, in order that the presence of a warship might not be detected from this cause. As there has been a tendency of late years to force the boilers of industrial plants, the inability to prevent the smoke nuisance under forced-draught conditions may have an important influence upon the increased use of liquid fuel.

(*j*) That the consumption of liquid fuel cannot probably be forced to as great an extent with steam as the atomising agent as when compressed air is used for this purpose. This is probably due to the fact that the air used for atomising purposes, after entering the furnace, supplies oxygen for the combustible, while in the case of steam the rarefied vapour simply displaces air that is needed to complete combustion.

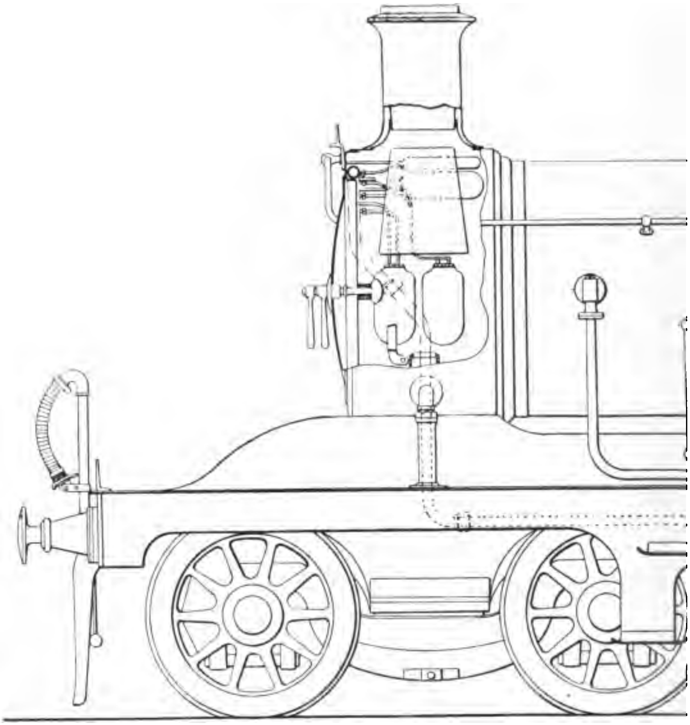
(*k*) That the efficiency of oil-fuel plants will be greatly dependent upon the general character of the installation of auxiliaries and fittings, and therefore the work should only be entrusted to those who have given careful study to the matter, and who have had extended experience in burning the crude product. The form of the burner will play a very small part in increasing the use of crude petroleum. The method and character of the installation will count for much; but where burners are simple in design and are constructed in accordance with scientific principles, there will be very little difference in their efficiency. Consumers should principally see that they do not purchase appliances that have been untried, and have been designed by persons who have had but limited experience in operating oil devices.

The results of the tests in the foregoing series of experiments are given in tabular form in the Appendix, and should be studied carefully.

CHAPTER IX.

OIL FUEL ON LOCOMOTIVES.

THE use of oil fuel on locomotives has made greater progress, so far as the practical and economic results go, than in marine work, although in the merchant service, as has been indicated, liquid-fuel practice has made great advances. Naturally, the conditions are not so onerous in railway work, and very close and continuous attention has been given to its application in this direction by Mr James Holden, the locomotive superintendent of the Great Eastern Railway. Mr Holden has brought his own burner and its use on locomotives very nearly to perfection, and every credit is due to him for having advanced the claims of liquid fuel as he has done for so many years. He thoroughly investigated the conditions under which oil fuel could be burnt most efficiently, and every detail to secure the best service was exhaustively dealt with. The outcome of all this effort and application has been the invention of a burner which, if not the most efficient and most economical available, stands in the forefront, and has formed the basis for the introduction of many others on the same principle. This burner (see fig. 18 *ante*) has already been described, and therefore can be referred to for details. At any rate, the success of Mr Holden's work has induced many English and foreign railway companies to adopt liquid fuel, and there is scarcely a single country in Europe that has not its liquid-fuel locomotives, while oil fuel has been adopted in India, Egypt, Japan, and, of course, America, especially in California. Another pioneer in this line of work was Professor Urquhart, who is the engineer on the Graizi-Tsaritsin Railway, in S.E. Russia. The work of Professor



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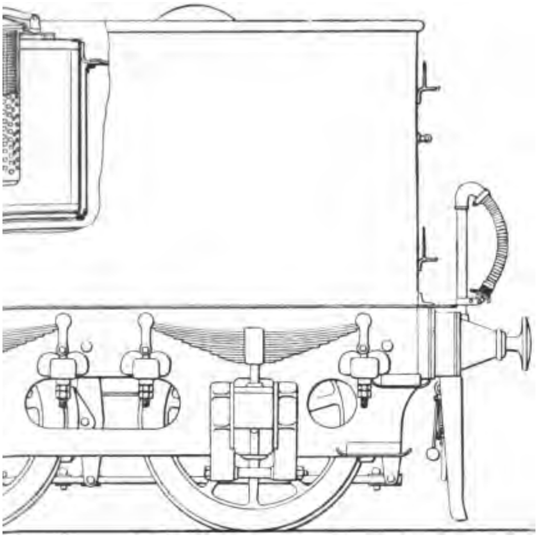

Urquhart has therefore also been of great benefit to the use of oil fuel on railways.

In a paper he read on the subject of liquid fuel, before the Institute of Mechanical Engineers, in 1899, he stated that he had under his superintendence 143 locomotives fired with petroleum refuse, besides 50 stationary boilers and some furnaces. The petroleum refuse used has, according to Professor Urquhart's calculation, a calorific value of 19,832 thermal units. Apparently, however, about 1200 thermal units should be deducted from this for the latent heat of the steam produced in combustion. The calorific value, as fuel, was therefore about 18,600 thermal units per pound, or the evaporative power is, say, 19½ lbs. of water from and at 212° per pound of fuel. The highest actual evaporation given in Professor Urquhart's paper was 14 lbs. per pound of oil, at 125 lbs. per square inch, from 60°. This would be equivalent to 16·8 lbs. from and at 212°, and, if it can be trusted, it is a very remarkable, though not impossible, result.

If the steam was not dry, then the real would be less than the apparent evaporation. It should be noted further that, in a locomotive with iron tubes, the evaporation is given as 12½ lbs. per pound of oil, and this is stated to be "the ordinary practice of locomotives." Professor Urquhart also states that at a trial at a print works at Moscow, with a stationary boiler of locomotive type, the evaporation was 13½ lbs. per pound of oil. The comparison here between coal and petroleum oil relates only to the calorific value.

To illustrate the present arrangement of Mr Holden's apparatus, a general outline elevation of one of a type of single-driver Great Eastern express locomotives is presented (fig. 35). This engine was built for working a special fast service of passenger trains between London and Cromer. The fittings are numbered, and correspond with the following references:—

A. Patent burners of the construction shown in detail in fig. 18.
B. Steam fitting supplying dry steam from the dome to the burners.
C. Regulating valves operating singly or together.
D. Oil-fuel pipes conveying the fuel from the tank on the tender to the burners.
E. Oil-fuel tank.
F. Warming coil used in cold weather to keep the oil fuel sufficiently liquid to regulate easily.

The oil fuel is injected through the front nozzles in a semi-sprayed condition by the steam admitted from one of the cocks of the steam fitting. The jet supplied by this is of annular formation, and induces hot air through the interior from the heaters in the smoke-box. To complete the atomising of the fuel, the steam passing the other cock of the steam fitting issues from a series of fine jets arranged round a hollow ring just behind the nozzle. These jets induce a considerable volume of atmospheric air (according to the velocity of steam permitted to pass the regulating cock) and, being directed at angles, deliver the atomised fuel equally over the grate area.

Writing on the use of liquid fuel in locomotives, Mr Holden stated, before the International Railway Congress held at Paris in 1900, that the most desirable position of the burners could only be arrived at by long-continued experiments, and so far the best results have been obtained as shown, with the burner eccentric to the holes in the fire-box. This setting of the burners conduces to economy in steam at the ring blower jets, as it utilises the steam to its utmost for air induction. It will be noticed that the ring blower attached to the burner is arranged eccentrically to the nozzle. The brick arch usually provided on coal-burning engines has been retained to obviate the too direct passage of the products of combustion to the tubes and to ensure a thorough combination. Also, the fire-door is provided with a deflector as shown, to direct downwards into the centre of the fire any air admitted at the fire-door, this practice being common to coal and oil burning engines. It will thus be seen that all the features necessary to the successful burning of solid fuel are retained.

With regard to the composition of the base or hearth over which the liquid fuel is to be burnt, if coal and liquid fuel are to be burned in conjunction, a thin layer of slow-burning coal will be found to be most efficient, with the damper of the ash-pan opened sufficiently to give an easy draught and ensure a bright fire. In this direction a variable blast pipe has been found of considerable benefit on the engines of the Great Eastern Railway, when burning liquid fuel in conjunction with coal, the opening of the exhaust orifice being enlarged by 30 per cent. in area, whilst if a return to coal alone is desirable, and a sharper blast required, a hinged cap provided at the top of the blast pipe and having a reduced area can be shut over the outlet, and the velocity of the escaping steam increased.

When liquid fuel is used alone, the procedure of working is somewhat as follows: steam is first raised in the boiler by a wood and coal fire kindled in the ordinary manner, and when from 30 to 40 lbs. pressure shows on the gauge the fire is levelled over and covered with a layer of broken fire-brick of not more than 3-inch cubes. This covering is spread so that it is thinnest about the centre of the fire-box, and well packed round the sides and corners. A few pieces of waste or wood are thrown in to cause flame, and the liquid-fuel spray is started by opening the steam supply to the central cones of the burners and admitting the liquid fuel through the regulating valves. At first the fire will appear dull and indifferent, with probably considerable smoke. After adjusting to approximately the requirements of the moment, the second steam supply is opened to admit steam to the jets of the ring blowers, sufficiently to induce the necessary air for complete combustion and to atomise and distribute the spray as already described. The fire soon clears and all smoke disappears.

The position of the burners relative to the grate will appreciably affect the noise of working. If too high, the introduction of the oil spray and air causes a series of minute explosions among the products of combustion from the fire below, and an intolerable hum ensues, whereas if the oil fire is maintained along the plane of the coal fire, the action is all but noiseless.

On the Great Eastern Railway coal tar and its by-products have been used as well as those from oil-gas plant, and petroleum distillation residues specially imported for fuel. With some 58 engines equipped, the means of storage and supply must necessarily be somewhat considerable, and the arrangements at Stratford for this purpose, which are the outcome of considerable experience, are the most complete in Great Britain.

The storage for supplying these engines with oil consists of a series of underground tanks, having an aggregate of 50,000 gallons capacity, arranged to receive the oil by gravity from the travelling tanks on the railway. A small rotary pump driven by a steam engine delivers the oil fuel into six large cylindrical reservoirs, elevated 20 feet above rail level, and having a total capacity of 42,000 gallons. Outlet pipes controlled by valves operated from a gallery above conduct the oil from these high-level reservoirs to filling posts or arms similar to ordinary locomotive water cranes, but somewhat smaller, for filling the tanks of the engines coming to the depôt for fuel. The whole plant is worked by four men, one of whom is exclusively employed on the night duty of filling the engines, whilst the other three, a chargeman and two assistants, are engaged during the day in pumping the oil, emptying the travelling tanks, and filling any engines arriving for day service.

Fifty engines, says Mr Holden, could be easily and expeditiously dealt with here, and the plant could be practically duplicated without increasing the manual labour. A main-line express engine can take 600 gallons of liquid fuel in a period of from four to five minutes. The whole installation is lighted by electricity, with portable lamps for the filling arms. It can readily be understood that the facilities of distribution are far greater with liquid fuel than with any system of coaling, no matter how mechanical. At the country depôts where liquid fuel is used, it is stored in underground reservoirs and is delivered to the locomotives by air pressure displacing it and driving it through the filling pipes. The air is pumped into the reservoir by the air brake pump of the locomotive, the driver and fireman manipulating the gear precisely as they would if renewing the water supply. The liquid-fuel tanks of the locomotive have a fine gauze strainer protected by a perforated cylinder of thin metal; this ensures a thorough clearing and filtration of the fuel prior to its entry into the tanks, pipes, and burners, and further acts as a safeguard against any danger from naked lights, should light oils or vapour happen to be present. This is a precaution more necessary when crude oil is used than when residues are employed, and on the Great Eastern Railway, where the latter are usually the fuel, the gauze is employed more for filtration purposes than for the sake of safety.

Engines similar to that illustrated have frequently made the through run from London to Cromer, 138 miles, in 175 minutes, with one stop of four minutes seven miles from the latter town, on a consumption of 190 gallons of tar residues (specific gravity 1·1), equivalent to 14·4 lbs. of oil fuel per train mile; to this must be added 6 cwts. of coal used to light the fire and raise steam, equal to 5 lbs. per mile, or a total of 19·4 lbs. per mile. On these journeys from 5 to 6 cwts. of broken fire-brick (old brick arches) are spread on the grate.

The system used on the Great Eastern Railway has been largely adopted in foreign countries. The administration of the Imperial Austrian State Railways have a total of 32 engines fitted for operating the Arlberg tunnel railway. The Western Railway of France have several engines on the suburban system of Paris so fired, as have also the Paris, Lyons and Mediterranean and the Paris and Orleans Companies. In the Far East numerous locomotives and stationary boilers have been fitted, countries adjoining the great oil-fields of Borneo and Java being particularly well represented in this respect. The demand for fuel has been met by petroleum companies supplying the crude oil minus its lighter constituents.

Wood is becoming more scarce and difficult to obtain in many districts, and in one case in America where this fuel has been superseded by oil, the difference in cost has been 33⅓ per cent. in favour of the latter, for when 1000 train miles on wood fuel cost $63·75 (£12, 15s.), the same mileage on liquid fuel has been secured with an expenditure of only $41·11 (£8, 4s. 5d.).

In South Africa the difficulty of obtaining fuel has somewhat retarded modern means of transportation, but liquid fuel burnt under the conditions described and with Mr Holden's apparatus has been successfully introduced as a convenient and satisfactory solution.

The carriage of liquid fuel in bulk to countries having no native coal or wood must be infinitely less in cost than that of solid fuel, for one ton of the former will equal two tons of the latter in useful effect, and here lies one of the greatest inducements to an extensive adoption.

From data which have recently been published, it will be seen that oil fuel is largely used on the Roumanian State

Railways. On this railway the Holden burner is almost exclusively adopted.

Of the total number of locomotives, 342 were fitted up to 31st March 1902 with apparatus for burning petroleum and lignite, and the remainder burnt wood or coal. Of the 342 locomotives which burnt petroleum residuals and lignite, 336 are fitted with apparatus of the Holden system, five with the Urquhart system, and one with the Körting system.

Of these locomotives, 17 burn residuals only, whilst the rest burn residuals and lignite. In the course of the year, 56 locomotives have been fitted with apparatus for burning petroleum residuals.

An apparatus for burning mixed fuel has been adopted, which enables an easy change to be made from residuals to coal and wood without the locomotive being put out of service.

The following are the quantities of fuel consumed during the year by the 482 different locomotives:—

Class of Fuel.	Quantity. Tons.
Cardiff coal	11,391·48
Westphalian coal	29,702·53
Silesian coal	393·83
Lignite from Prahova and Dambovitza	92,024·41
Lignite from Bacau (Trotus)	416·21
Petroleum residuals	27,051·02
	Cubic Metres.
Wood	221,119

This fuel has cost on an average 26·25 francs per ton, and if we add to this the cost of handling, superior tendence, losses, etc., the average cost of a ton of fuel will come to 27·27 francs.

The consumption of oil fuel during the last ten years has, needless to say, greatly increased, and while in 1891 only 1464 tons of petroleum residuals were used, no less than 27,051 tons were consumed during 1902.

A design of an oil-fuel apparatus employed on a Californian railway is also presented here (fig. 36). The inventor is Mr W. N. Best, superintendent of the Los Angeles Railway.

The oil burner used differs chiefly from others in that the oil channel is below the steam atomiser instead of above it. The nose-piece of the atomiser is held in place by a bridle, so that it can be quickly removed if the steam passages become stopped. There is also an automatic release valve for draining the steam pipes and passages when the burner is not in use. A spiral spring acts to raise this drainage valve, which remains open until steam is turned on in the burner, when it closes automatically. This prevents water from reaching the refractory walls and arch and injuring them.

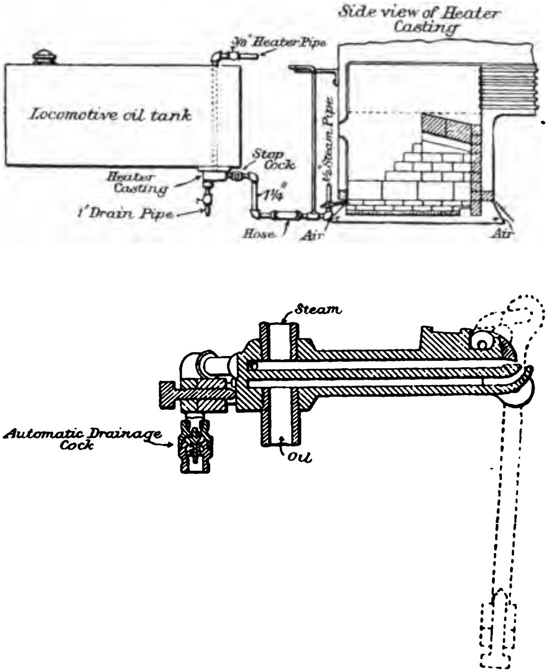

FIG. 36.—Best's oil fuel apparatus.

An inverted arch is used, similar to those commonly employed, except that the hole for the admission of air is just at the back of the front refractory wall. This location is the result of actual trials. The inverted arch is lined with fire-brick at the rear, and around the air cavity an angle iron is riveted in order to hold the fire-bricks in place.

The refractory arch is of bricks, 9 inches thick, fitting closely to the front refractory wall and resting on two wedges which give them the proper pitch. The highest portion of the arch is level with the lower flue, and the arch is made one-third the length of the fire-box.

Oil fuel is also employed on the Madura street tramways in the Dutch Indies. The oil is supplied by the Dordtsche Petroleum Company, and is of a somewhat viscid character. In order to warm up the residue and so increase its fluidity. a pipe is coiled around the sieve in the reservoir, which pipe can be supplied with steam from the main boiler by turning a cock from the supplementary boiler by means of a pipe and a three-way tap. The water condensed in the coiled pipe can be blown off on to the wheel rims in order to reduce the amount of wear. The actual burner is placed below the iron fire-box, and is bolted on to the ash-box with screws. The oil-fuel pipe opens into the left-hand side of the burner, the steam pipe discharging into the top. The steam may be obtained from the main boiler by turning on a cock, or else from a supplementary boiler by means of a three-way cock and pipe.

For simplifying the service, an equilibrium valve set at 5 to 6 atmospheric pressure, and controlled by a pressure gauge, is fitted to the pipe conveying steam to the burner. Between the boiler and this valve is a sieve (readily accessible for cleaning) which retains all solid matter (fragments of wood, stone, etc.) carried by the steam. The supply of fuel is regulated by a hand-wheel mounted at a convenient height on the boiler and controlling the feed cock.

The burner used on the engine was of the Urquhart type, with a few modifications.

The results furnished by these locomotives were very favourable. The charging of the reservoir with 66 gallons of residuals supplied by the Dordtsche Company occupied 15 minutes, the fuel being warmed up by steam from a supplementary boiler to 45° C. The locomotive boiler was filled with cold water, and the burner was turned on gradually. The pressures recorded were:—

At	2.50	4.10	4.23	4.32	4.40	4.57	4.59	5.8	5.15	5.21 o'clock.
Atmos. pressure	0	1	2	3	4	5	6	7	8	9

From 4.10 p.m. the locomotive's own steam was used in the burner, and at 5.24 a pressure of 9½ atmospheres was obtained, the consumption of fuel amounting to 6·6 gallons. The trial run from Bangkalan to Kamal gave the following results:—

Mean speed per hour	10·2 miles.
Mean pressure of steam	8·2 atmos.
Consumption of liquid fuel	15·5 galls.
Consumption of water	164 ,,
Length of track	11·2 miles.
Cost of residue per 220 galls.	25s. 3d.
Water evaporated per unit vol. of residue . . .	9·6 units.

The average consumption of liquid fuel on the trial trip was 12·10 gallons, with a train weight of 35 tons, the cost being less than 1d. per kilometre, while the expense with coal amounted to $\frac{19}{16}$d.

In order to satisfy themselves that fuel oil was as well adapted as coal for firing locomotives having to traverse a mountainous country, the Japanese Government ordered tests to be made on its Shin-Yetsu line, which is operated in a mountainous part of the country. The results of this test were considered as satisfactory as those made on roads traversing a comparatively level country. The fuel oil used in the tests on the Shin-Yetsu line came from the district known as Northern Echigo. The Japanese Government intends also, it is reported, to use oil fuel on the Tokaido line, as a portion of this line runs through the Hakone passes, where there are many tunnels, which cause the heavy smoke and gases from the coal burned in the engines to unpleasantly accumulate. The Ohugwai Shogyo Company, it is said, is still contemplating a change from coal to fuel oil on its locomotives.

In another paper read by Professor Urquhart some years ago, he gave figures representing the cost of transforming a locomotive burning coal to one capable of burning oil. The cost, he estimates, would amount to £39, 10s.; this at least is the sum which he himself expended on the conversion of an engine on the Grazi-Tsaritsin Railway in Russia. This price applied to a six-wheeled engine. In an eight-wheeled engine, in which the coal space had to be increased, the outlay amounted to £76, 18s.

In the six-wheeled engines the average cost of fuel per engine mile was reduced from 7·64d. for coal to 4·43d. for petroleum, or 42 per cent.; in eight-wheeled engines the reduction was from 11·02d. to 5·84d., or a saving of 47 per cent. In the former type of engine the equivalent of 100 tons of coal was 55 tons of petroleum, while in the eight-wheeled engine 50 tons of petroleum displaced 100 tons of coal.

CHAPTER X.

OIL FUEL FOR METALLURGICAL AND OTHER PURPOSES.

OIL fuel should form an unequalled medium for smelting metals of various descriptions, especially the more valuable ones. The cleanliness of the fuel alone recommends it for use in smelting, and it has been adopted in quite a number of instances in this and other countries. The great objection to it is again its cost, though the economy that can be effected in the metal itself is one point which would largely counterbalance it. Oil fuel has also found extensive use in smelting the heavier metals, and we cannot do better than give a brief record of these applications here.

In reference to the different purposes to which liquid fuel has been put, it is of great interest to know that as far back as 1888 Mr James Riley, the well-known steel-works manager of Scotland, in conjunction with Mr F. W. Dick, introduced an apparatus for burning liquid fuel in regenerative furnaces. The furnace is described in the specification as follows:—The improved furnaces are of the kind in which gaseous fuel is used, and in connection with which heat regenerators are employed. The regenerative chambers are buildings detached from the main furnace building, and where four are used, as will generally be the case, are arranged in two pairs at the ends of the space, with the furnace between them. Each chamber might be wholly detached, or each pair may be formed in one building, side by side, or one above the other. The chambers are by preference built so that their upper parts communicate directly with the furnace, being close to the furnace, or connected with it by very short flues. Each regenerative chamber is by preference of a cylindrical form, and consists of an iron or steel shell lined with fire bricks. The communications with the chambers used respectively for heating the gas and the air are controlled by separate valves, and sight-holes are provided to allow the internal condition being ascertained at any time. The tops of the chambers are by preference made removable to facilitate repairs; and each entire chamber may be made portable, so that it can be raised for the purpose of emptying out the chequer-work with which the chamber is filled as usual.

Four years previous to this, Mr Ludwig Nobel, of St. Petersburg, Carl Wittenström, of Motala, and E. Faustman and P. Ostberg, of Stockholm, invented an apparatus to be employed in burning naphtha or other volatile liquid, applicable especially for melting metals which are difficult of fusion. This patent is described as follows:—Hollow trough-like fire-bars are employed. They are placed one above the other. The naphtha or combustible liquid is always kept to an equal depth on the fire-bars during the firing. This is conveniently accomplished by a supply and overflow as follows. There is a small pan cast in one piece with the fire-bar and in connection with the trough-like hollow therein. The naphtha or liquid is supplied to the pan by a fuel pipe or by the overflow from the bar above, and the overflow pipe is fitted in the same pan. These overflows regulate the quantity of naphtha and the equal distribution of it on the different fire-bars. The draught is obtained simply by a chimney. The flame passes from the fire-bars into a chamber for the purpose of mixing the combustible gases with air, which is also admitted to the chamber. From this chamber the flame passes forward into the body of the furnace through a narrow passage or passages, for the purpose of effecting a more complete mixing of the gases with the air. This arrangement causes the temperature to be raised considerably, and is quite indispensable to a complete and smoke-free combustion.

Petroleum residue (sp. gr. about 0·93) is used as a fuel for smithy fires[1] in a number of German and Russian works, the later especially. The arrangement shown (fig. 37) has now been in use for some time in the railway repairing shop at Ufa; and prolonged experience with oil fuel has shown the system to possess the following advantages:—(1) The petroleum hearth does not give off any noxious sulphur gases; (2) it occupies only a small amount of space, so that more smiths can be accommodated in the shop than is the case with coal hearths; (3) it can be easily fitted; (4) is cheapest; and (5) much more productive, especially in nail smithies, since a number of pieces of iron can be heated together, and the work goes on continuously, whereas this is impossible with coal fuel.

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[1] Translation in *Petroleum Review*.

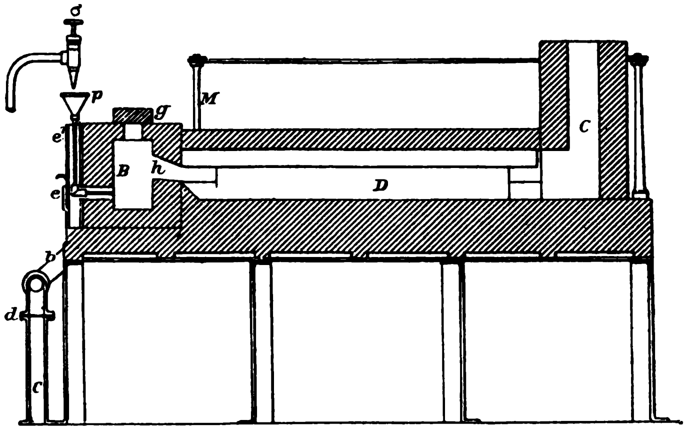

FIG. 37.—Longitudinal section of metallurgical furnace.

The cost of producing a ton of wrought-iron works out as follows:—

	A Francs.	B Francs.	Total Francs.
With residuals . .	48·61	28·53	77·14
,, coal . . .	107·76	4·80	112·56

Here A represents the cost of fuel, and B that of labour. Consequently, by the use of residuals a saving of 59·15 francs is effected in respect of fuel, and 31 per cent. on the total outlay. For performing the work in 10 hours, 33 smiths are needed with oil firing, whereas with coal 40 men are required, the former being therefore more productive by 17·5 per cent. At the Ufa works a smith earns about 3·73 francs (roughly 3s.), and, apart from the prime cost of the metal, the production of a ton of wrought goods works out to $77·14+(33\times 3·73)=200·23$ francs for the petroleum hearth, and to $111·56+(40\times 3·73)=260·76$ francs for the coal hearth, the latter being therefore the more expensive method by 60·53 francs per ton.

Formerly, the hearths in the Ufa repairing shop, eight in number and employing 20 smiths, were fired with coal exclusively; but as the work increased and more accommodation became necessary, oil firing was introduced, and at present there are five hearths at work (two of them double), employing 30 hands.

The petroleum smithy hearth (fig. 37) consists of a solid angle-iron framework, mounted on iron feet. The framework carries a course of brickwork, 4½ ins. high, at the two extremities of which are the generator B and the flue C, the iron being heated in the part D. The generator B consists of a jacketed iron case, into the two opposite sides of which debouch the branches of the air conduit *c*, which is fitted with a damper *d*. The two walls of the case are provided with the semicircular apertures e, e^1, the former fitted with a damper and serving as a peephole for watching the progress of the fire. The atomiser consists of two iron pipes, one of which is wedged firmly into the inner wall of the case and serves as the air-blast nozzle; whilst the other is formed of two parts, set at right angles, one part acting as the oil nozzle and the other terminating in the smaller funnel *p*, which is filled with oil from the tap *o*. The generator case is open below, and the sole purpose of the side walls is to strengthen the fireproof lining. The latter is provided with two fireproof orifices, *g* and *h*, of which the first-named serves for the ignition of the mazout on starting to work, whilst *h*, which is taper and slopes down towards the space D, conducts into the latter the gases produced and ignited in the generator B. In order to increase the retention of heat in D and ensure the better heating of the work, the bottom of the hearth is filled with broken fire-brick. The chamber D is fitted with a cover of fire-brick set in an iron frame, this cover being arched to facilitate the access of the flame to the material to be heated.

In working these hearths, the oil fuel is lighted by throwing a small bundle of burning greasy rag through the orifice *g* into the generator, the register in the air pipe being opened a little, and a fine stream of mazout allowed to run into the funnel *p* by turning on the tap *o*. The oil encounters the current of air, is atomised, and ignites at the burning rags. The complete admixture of oil and air is assisted by the position of the orifice *h*, which is on a somewhat higher level than the atomiser. Until the walls of the generator are fully heated, the flame is allowed to stream through *g* and *h*, but as soon as the hearth begins to get white hot, the hole *g* is closed with a stone or a lump of clay. The temperature of the hearth can be adjusted to working strength by regulating the air damper and the oil tap, the best results being obtained when the air pressure in the pipe measures 2 ins., water gauge, and 1¼ ins. in the generator; under these conditions the consumption of oil is 40–42 lbs. per hour. The double walls of the generator case serve to heat the incoming air, and thus economise fuel; the combustion is complete and smokeless.

The hearth, as illustrated, will find employment for six smiths working together, two of whom can be engaged in welding pieces of medium size, without being in the way of the rest.

For the manufacture of sheet iron a petroleum furnace has been in use which differs very little in construction from the usual gas furnace. At the back of the arch is an opening which admits the oil sprayer. This sprayer is so arranged that it can be moved in any direction, while there is no possibility of air entering, except through the sprayer. The products of combustion travel through the side flues, and thence to the chimney. Each furnace has its own chimney, the diameter of which is 0·65 of a metre, and the height 13·5 metres. As a rule the chimney is shorter, as with petroleum fuel less draught is required, and the fire can be so regulated that practically no smoke is observable.

At the back of the furnace an opening is made to regulate the temperature and to increase or decrease the supply of fuel or air. Care must be taken that the sprayer is not more than between 500 and 600 mm. above the iron to be heated. As a rule the petroleum furnace is heated very rapidly—that is, it is ready for working in from 2½ to 3 hours, and not more than from 12 to 15 poods (from 4 to 5 cwts.) of petroleum are required for every three ingots dealt with; the gas furnace, on the other hand, generally takes from 9 to 10 hours to prepare for working. In the petroleum furnace the ingots are put in the same way as the gas or wood furnace, with this difference, that whereas the ingots in the two latter descriptions of furnace are laid on their sides, in the former they are laid flat. The ingot that has come from the petroleum furnace is evenly heated throughout, the result being that the percentage of spoilt ingots is considerably less than when gas is used. Not only this, but the wear and tear of the rolling mills is very much reduced, as, for instance, in 1896–97, when wood fire was employed, out of five rolls used, four were broken; while in 1897–98, when petroleum was used, not a single roll was broken, and the work turned out was superior. The results were due to the use of petroleum as fuel. By the use of gas fuel, that part of the ingot which lies at the back of the furnace always attained a higher temperature than that in front, and when Siemens-Martin steel has been used the oxidisation has taken place in the back part of the ingot. In the petroleum furnace, on the other hand, the temperature is always regular throughout, and with Siemens-Martin steel no trace of oxidisation is apparent. It may be doubted whether it is possible to distribute the heat evenly over a space of 1 square metre, as the petroleum flame is concentrated in the centre, but the fact is, that the flame, being forced by pressure, is spread over the whole area, and this is proved by the fact that, whereas in 1896–97 the iron sheets showed a difference of thickness amounting to 2 mm., the front measuring 24 mm. and the back 26 mm., or a difference in weight between the front and back of the ingot of 2 lbs., since petroleum has been introduced this difference has entirely disappeared.

The quantity of fuel used for the petroleum furnace represents from 70 to 72 poods of residuals, or approximately 1 pood per hour per ingot. The quantity of iron treated averages 440 poods in the twenty-four hours, the process being repeated three times, and sometimes four or five.

In the year 1901, a small liquid-fuel furnace for metallurgical purposes,[1] and primarily for smelting tungsten and copper ores, was erected and worked by Messrs Holloway, Lake & Currie, at Garford Street, Poplar. The furnace was a small one of the reverberatory type, and the method of supplying the oil, pulverising and igniting it, was of the simplest. The burner, in fact, was nothing more than a simple mechanical device for injecting

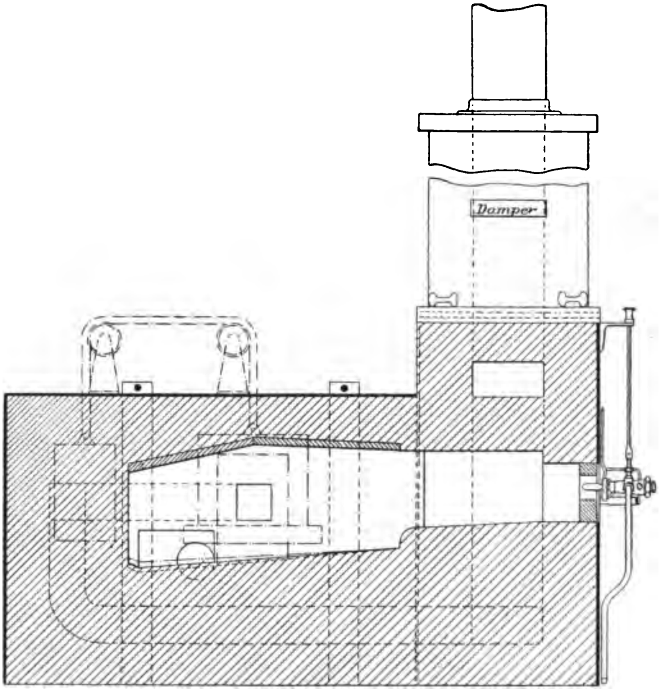

FIG. 38.—Longitudinal section of Holloway's smelting furnace.

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[1] *Petroleum Review.*

oil and air into the furnace. One of the chief points about this apparatus was the small size of the combustion or gasifying chambers, namely, 8 × 7 × 9 ins., which may be seen from the sketches given (figs. 38 and 39). The furnace was worked by a blast obtained from a Roots blower, and heated by the waste heat from the furnace. The system employed permitted of a low-pressure air-blast, though a wide range of temperature can be obtained, while there is no necessity for smoke-stacks. The results of the working of this furnace proved that a reverberatory furnace having a hearth 5 ft. by 2 ft. 6 ins. could be run at a temperature just below the fusion point of cast-iron, for a consumption

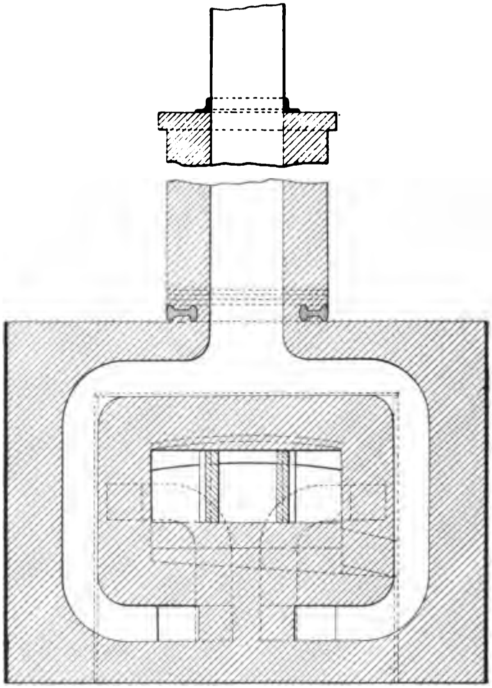

Fig. 39.—Transverse section of Holloway's smelting furnace.

of 2·8 gallons per hour, and an air pressure of from 2 to 3 ozs., and that a high-temperature crucible furnace, capable of holding three 150-lb. pots, has been run for seventeen consecutive hours at a temperature ranging between 1700° and 2000° C., with a consumption of 4·75 to 5·0 gallons of Borneo oil per hour, and a cold blast of 16 ozs. An important development in the use of liquid fuel for small blast furnaces consists in the fitting of an oil supply to the tuyeres to the cupola furnace by Messrs Holloway. Those who have to do with cupola work know the tendency there is for the charge to hang up. To obviate this, it is only necessary to inject a little oil at the mouth of each tuyere. The oil is at once converted into gas, and burns throughout the whole charge, so that fusion usually proceeds at once.

A crucible furnace for the smelting of brass in use in the United States, described in an American contemporary, is capable of fusing 40 lbs. of brass in about thirty minutes with half a gallon of liquid fuel, which means at about a cost of one penny. The action is extremely simple. An upper vessel contains the main oil supply. From there it falls by gravity through the cock into the filter vessel. The cistern being air-tight, the level in the filter vessel is always the same—that is to say, it just covers the mouth of the vertical tube. From the filter vessel the oil descends through the filters, passes into the small pipe, through a valve just beneath the filter vessel, then through a second regulating valve, and out by the down-turned nozzle. The air-blast enters by the tube, which has a hole at the end and a slot underneath. As the oil trickles over the tube, it is blown by the air issuing from the slot to the bottom of the combustion chamber, where it is partly vaporised and partly burned. The resulting flame and gases, issuing by the orifice, circulate round the crucible, where combustion is completed, and the waste gas passes out through a hole in the lid. When a complete charge cannot be packed in the one crucible, a second clay warming cylinder is used to prepare the extra amount.

It ought to be noted that, as there is no passage less than ¼ inch in diameter, the apparatus is quite free from choking, so frequent in small spray burners, and as whatever vaporisation takes place is effected in a large combustion chamber in the presence of air, any non-volatile constituents of the fuel are immediately burned, entirely overcoming the caking difficulty.

The smelting of iron ore by the use of oil has often been suggested, and endeavours have been made towards this end, but so far these have proved neither mechanically nor commercially successful. A process[1] has been devised recently by Mr E. Riveroll, of Los Angeles, Cal., which is illustrated herewith.

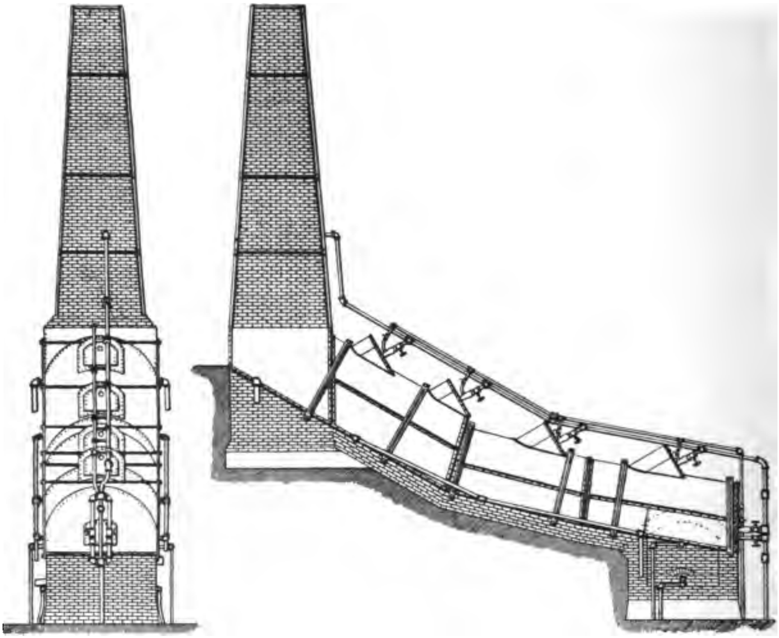

FIG. 40.—Sectional views of furnace for smelting ore with oil.

The ore and flux are introduced through a charging door directly under the stack, and pass down the inclined bottom of the furnace, the molten metal and slag being collected in the crucible at the lower end, from which they can be tapped off. The oil is introduced, with steam, through a number of jets placed on top of the furnace, as shown. The furnace described is 40 feet in length and 2 feet in the clear, inside.

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[1] *Petroleum Review.*

The inventor points out that during the past decade numerous attempts have been made to accomplish this process. It is true pig iron has been secured by experimenters with oil as fuel, but in no case has more than 150 lbs. of the charge been reduced at one time, and even then coke or charcoal had to be introduced to the extent of 10 per cent. or thereabouts in order to bring about the necessary chemical reaction. Heretofore all efforts to produce this important material in commercial quantities, using only crude oil as fuel, have failed, because of the apparently insurmountable difficulties in the way. Chief among these was the getting rid of the oxygen in the iron ores,. and the application of the heat directly upon the entire body of the ore to be reduced.

This process is both simple and inexpensive, being less complicated than the cupola or upright smelter, and requiring none of the cumbersome machinery incidental to the hoisting of both ore and fuel to the top of the flue.

On August 19, 1902, Mr Riveroll made a trial run in his 50-ton capacity experimental smelter at Tropico, Los Angeles county, California, in the presence of Professor Joseph Kirkham, general manager of the Pacific Art Tile Works, and several other responsible parties. This run was so successful as to place the invention beyond the bounds of mere experiment. For more than half an hour molten metal ran out in a steady stream, and then the furnace was shut down, as its unqualified success had been demonstrated to the entire satisfaction of all concerned. The resultant slag consisted of 45 per cent. silica and alumina, 50 per cent. of lime, and 5 per cent. of iron and other elements.

The chief claim urged by the inventor in favour of his smelter is its economy. Taking the experimental run referred to above as the basis of this claim, the following figures taken at the time furnish sufficient data to substantiate all claims of economy:—The analysis of iron ore used showed metallic iron, 56·7; silica and alumina, 13·3; sulphur, 1·4. The analysis of the limestone (flux) was:

lime, 52·5; silica, 6·3. The quality of oil was specific gravity 20·5. Two barrels of this oil were necessary, on an average, to reduce one ton of the charge. With oil wholesaling in the West for 60 cents per barrel, and the cost of ore (not to be less than 50 per cent. metallic iron) not more than $3 per ton, pig iron can be produced for $10 per ton or less.

In a paper read at the beginning of the year by Mr A. von der Ropp, on the subject of the use of crude oil in smelting, before the California Miners' Association, at San Francisco, he states that at the works of the Selby Smelter 4 roasting furnaces are used, with a total of 11 burners; 1 matting furnace, with 3 burners; 1 copper furnace, with 1 burner; 14 lead furnaces, with 14 burners; 13 zinc retorts, with 13 burners; 3 cupel furnaces, with 3 burners; 1 antimony furnace, with 1 burner; 1 furnace for smelting fine silver, with 1 burner; total, 47.

In all of these furnaces the use of crude oil has brought about a saving of from 40 to 60 per cent. in the cost of fuel over coal. And this does not represent all the benefit to be derived from the use of liquid fuel in metallurgical establishments.

Mr Ropp also pointed to the ideal conditions prevailing in the roasting furnace when liquid fuel is used. Once the flame is regulated by properly adjusting the oil and steam inlets, we have, he says, a clear flame, with not a trace of soot in the roasting chamber; and this ideal condition continues for twenty-four hours per day, enabling the sulphur in the ores to combine with the oxygen in the air during every fraction of a second. This means that we can crowd a roasting furnace using oil far beyond the capacity of a furnace using coal, and still we can produce a good end roast with the same percentage of sulphur remaining. This means that we can reduce the cost of fuel, labour, and repairs per ton of ore treated.

In the reverberatory type of furnace, the roasted ore is subjected to a white heat to produce a quick sintering and melting down of the charge. The aim in this furnace is to produce, first, "a copper-iron matte, which acts as an accumulator for the precious metals"; and, secondly, "a slag which is formed from the earthy components of the ore." As matte is a compound of sulphur and heavy metals in fixed proportions, it is self-evident that the percentage of copper in the matte depends on the amount of sulphur remaining in the charge.

Suppose, now, that we use coal as fuel in the matting furnace, we will have a reducing atmosphere whenever the fireman gets busy and fills the grate with fresh coal, thus producing an incomplete combustion for a certain length of time. During this period no sulphur can be oxidised by the oxygen of the air. With oil we have an oxidising atmosphere during every second, and consequently we find that we produce a higher grade copper matte in a furnace using liquid fuel than we can possibly produce in a furnace using coal. On the other hand, if it should be desirable to have a reducing atmosphere in metallurgical work, it is easy to change from an oxidising atmosphere to a reducing one in an instant, by either choking the air inlet to the furnace, or increasing the flow of oil to the burner.

As the dimensions of metallurgical furnaces are variable ones, flames of many different sizes are required for metallurgical tools. For instance, at Selby, the extreme lengths of flames used are 8 inches and 6 feet. In the zinc retorts, which are the smallest furnaces, a flame of 8 inches is needed. In the large matting furnace, 35 by 16 feet in the clear, a flame of 6 feet or even more in length is needed. The burner has to be adapted to the furnace and to the work to be performed. Hence you will find at metallurgical establishments a great variety of burners, or at least a great variety of sizes of burners, and there is probably no better all-round burner than the one made of two concentric pipes, the smaller one being the oil pipe, and the larger one the steam-carrier. By this arrangement the oil pipe is steam-jacketed, and the temperature of the oil is raised to such a degree that its fluidity is very much increased, and part of the lighter oils become gases. All this tends to break up, more or less, the viscous oil into minute particles, which ignite readily when brought in contact with the oxygen of the surrounding atmosphere.

"During the last few years," concluded Mr Ropp, "I have been repeatedly approached by parties asking why I do not use oil in the blast furnace, and the only answer I can give them is the following:—Solid carbon plays a very important *rôle*, especially in the upper level of the blast furnace shaft. Its function, especially with the fine ores, is largely to limber up the charge and allow the flow of gas to penetrate the charge evenly; besides, incandescent carbon has certain functions to perform in the blast furnace, which are of a chemical nature, and which need not be discussed. If coke or charcoal should be entirely replaced by oil in the blast furnace, the blast furnace charge would very likely become too dense to allow the combustion gases to escape freely."

A portable rivet-heating furnace is also illustrated herewith (fig. 41), which has been specially designed for Holden's system of liquid fuel burning, and operated by compressed air or steam, whichever is most convenient. The regulating valve C is coupled to the compressed air or steam supply pipe and the injector. This valve enables the exact amount of air or steam to be admitted to the injector for spraying and atomising the fuel.

The oil passes from the tank to the regulating valve on the injector, the whole apparatus being under absolute control of the operator.

Rivets are fed in at the top hole of the furnace, where they are first heated by the waste gases, and then passed through to the lower chamber, where they are submitted to the full heat of the liquid fuel. When sufficiently heated they are removed through the bottom door.

To start the furnace, place some lighted oily waste, or similar combustible material, in the lower chamber, and then open the valves very gradually, and regulate the fuel until a clear fire is obtained without smoke; as the brickwork becomes hotter, more liquid fuel may be used as required.

A brass-smelting furnace in use at the Grazi-Tsaritsin Railway works in Russia is also worked with liquid fuel. The furnace is of the well-known make, having a drop bottom, which, however, is not used, as there is no new residue. One blast tuyere is used for each furnace, and is set tangentially, thereby giving a whirling motion to the flame, which, coming in contact with the white-hot firebrick lining, ensures complete combustion of all the particles it contains. The blast is cold, and supplied by an ordinary fan. Besides keeping a much cleaner foundry, free from sulphurous fumes, the adoption of petroleum in place of coke has resulted in a sensible economy in fuel, as well as in

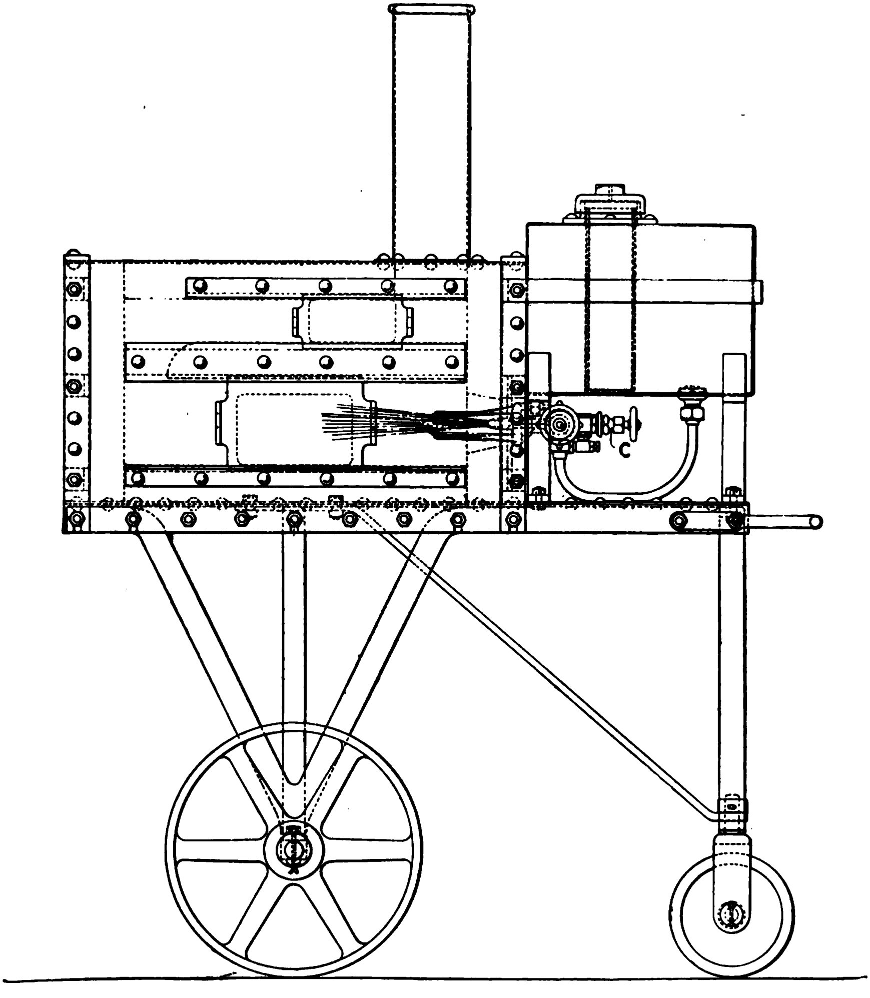

FIG. 41.—Riveting furnace using oil fuel.

time occupied in smelting. With coke 40 lbs. of brass castings were made with 35 lbs. of fuel and 10 per cent. loss of metal; with petroleum 40 lbs. of castings are produced with 18 lbs. of fuel and only 6 to 7 per cent. loss of metal, and with 25 per cent. saving in time.

Another very satisfactory arrangement of utilising fuel oil for assaying, etc., is made by the Bickford Burners Co., of Camborne, and some interesting figures are published by the makers. The furnace can be started in 15 seconds, and 40 lbs. of brass melted in 30 minutes, with an expenditure of half a gallon of fuel oil. A fan blast of not less than 2 ins. pressure is necessary for small brass casting, 5 ins. to 8 ins. for general work, and 8 ins. to 12 ins. for fine brass and cast-iron.

In a large foundry using this apparatus the comparative cost of coke and oil for melting 40 lbs. of brass is given as under:—

COKE.	*d.*	FUEL OIL.	*d.*
¼ cwt. oven coke at 1s. 3d. .	3·75	¾ gall. oil at 2½d. (bought in small quantities). . .	2
3½ per cent. waste of brass .	8·4	1½ per cent. waste of brass .	3·6
Crucible (20 charges per crucible, 5s.)	3	Crucible (30 charges per crucible, 5s.)	2
	15·15		7·6

Showing a saving of over 50 per cent., exclusive of any advantages of labour, etc.

The U.S. Government adopted oil as fuel on the *Mills*, one of the world's two greatest ocean-going dredgers, which are engaged in deepening and straightening the waterway from the Eastern Channel to the Narrows in New York Harbour.

Before the *Mills* was adapted for the use of liquid fuel, the sister ship, the *Thomas*, burning coal, was engaged alone in dredging operations, which the Government engineers calculated would require something above four years for completion, but now, with the addition of the *Mills*, the same engineers predict that the work will be finished in less than half the time originally set. At no time has fuel oil proved its value more satisfactorily than in its employment on the dredger *Mills*.

A sectional view and plan (fig. 42) of a small crucible furnace which has been designed by Messrs Taite & Carlton, and which has given excellent results in working, is also introduced here.

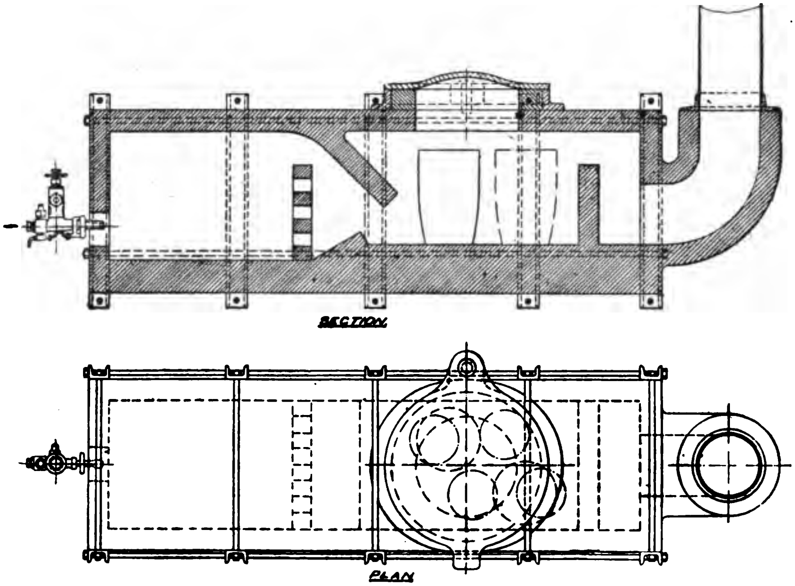

Fig. 42.—Section and plan of crucible furnace designed by Messrs Taite & Carlton.

CHAPTER XI.

OIL FUEL FOR DOMESTIC PURPOSES.

THE employment of liquid fuel for domestic purposes has up to the present time received little attention, for the reasons that absolutely new equipment would be required, involving possibly some structural alterations in existing dwelling-houses, that the price of oil, at the present time, prohibits its use on so small a scale, and that popular prejudice is against the displacement of a fuel which has become recognised as an indispensable part of domestic life. There is a simplicity about the matter of putting a shovelful of coal on the fire, while the use of tanks and taps appeals to the ordinary householder as being too complicated for safety and cheapness. Certainly, some invasion has been made into this primitive method by certain classes of stoves which are independent of wicks, and produce their heat by the consumption of the oil vapour given off.

The only countries in which any attempt has been made to introduce liquid fuel for domestic purposes have been America and Russia, where the supply of oil is cheap and readily obtainable. Even here, however, the application is not at all on a large scale, and there is an aversion to its use on account of erroneous ideas that it is impossible to burn it properly in ordinary stoves, and that it will give off smoke and soot, and entail dangers not present in the use of coal. So settled is this conviction in Russia that even the municipal authorities of such towns as Baku, Tiflis, and Petrovsk, etc., have issued strict injunctions prohibiting its use in dwelling-houses.

In burning liquid fuel, it is always necessary to have a good draught, so that it is rarely possible to adapt existing stoves to petroleum burning.

Mr Baskakoff, a Russian engineer, who has studied this question of the domestic use of liquid fuel, comes to the conclusion that a firing chamber specially adapted for petroleum burning and a certain construction of flues are of as great importance for complete combustion as the form of the burner itself. With these principles in view, he set about solving the problem, and ultimately produced complete and smokeless combustion of the oil, without the aid of pulverisation, and with the conditions prevailing in ordinary domestic stoves. The latest burner introduced by Mr Baskakoff gave a soot formation of only 0·0003 per cent. of the total amount of fuel used. For this design he was awarded the gold medal of the Imperial Russian Technical Society.

APPENDICES.

TESTS MADE BY THE U.S.

No. 1.—Test of Oil Fuel in a Hohenstein

[Six hours' duration with forced

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.			Oil Spraying Air Pressure per square inch.
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Gases at Base of Stack.	
	lbs.	deg. F.	deg. F.	deg. F.		ins.	deg. F.	deg. F.	deg. F.	lbs.
11 a.m.	275	120	402	302	0·982	2·125	84	117	..	3·20
11.15 a.m.	275	112	402	302	·983	1·75	..	118	663	3·11
11.30 a.m.	275	112	402	303	·983	2·5	..	116	..	3·14
11.45 a.m.	275	110	402	304	·984	3·5	..	118	705	3·23
12 m.	275	122	402	302	·982	2·75	86	119	..	3·17
12.15 p.m.	275	122	402	303	·983	1·75	..	119	709	3·17
12.30 p.m.	275	120	402	304	·984	2	..	120	..	3·23
12.45 p.m.	275	112	402	304	·984	3	..	121	717	3·23
1 p.m.	275	118	402	304	·984	2·13	86	121	..	3·23
1.15 p.m.	275	120	402	304	·984	2·75	..	122	715	3·17
1.30 p.m.	275	120	402	304	·934	2·75	..	122	..	3·11
1.45 p.m.	275	118	402	304	·984	3	..	122	712	3·23
2 p.m.	275	123	402	303	·983	2·25	86	122	..	3·23
2.15 p.m.	275	124	402	304	·984	2·25	..	122	711	3·17
2.30 p.m.	275	122	402	304	·984	2·5	..	122	..	3·23
2.45 p.m.	275	126	402	304	·984	2	..	122	714	3·23
3 p.m.	275	122	402	303	·983	2·75	86	122	..	3·23
3.15 p.m.	275	120	402	304	·984	2·13	..	122	706	3·23
3.30 p.m.	275	128	402	302	·963	2·13	..	122	..	3·23
3.45 p.m.	275	129	402	303	·963	2·13	..	122	690	3·23
4 p.m.	275	124	402	303	·983	2·13	85	122	..	3·23
4.15 p.m.	275	124	402	304	·984	2·13	..	122	704	3·23
4.30 p.m.	275	121	402	303	·983	2·13	..	124	..	3·23
4.45 p.m.	275	124	402	303	·983	2·13	..	123	709	3·17
5 p.m.	275	125	402	304	·984	2·125	85	124	..	3·17
Average	275	120·7	..	..	·9834	..	85·4	121	704·6	3·20

State of weather, bright sun, clear sky.

Barometer at noon, 30·02 inches.

Kind of fuel, Beaumont oil.

Revolutions of fan blower, 327 per minute.

Revolutions of Root blower, 126 per minute.

Draught openings into furnace, 666 square inches.

9.10 a.m. Two middle burners lighted. Root blower driven by steam from small independent boiler.

10.05 a.m. Steam pressure in main boiler, 100 pounds. All auxiliary machinery begun to be driven by steam from main boiler. All six burners alight.

Smoke very uniform and much thinner than corresponds to chart No. 1.

LIQUID FUEL BOARD.

WATER-TUBE MARINE BOILER, June 11, 1902.

draught, using air burners.]

Draught Air Pressures in Inches of Water.					Flue Gases.			Oil.		Water.	
Fire Room.	Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	CO_2.	O.	CO.	Burned per Hour.	Total Weight Burned.	Fed per Hour.	Total Weight Fed.
					%	%	%	lbs.	lbs.	lbs.	lbs.
1·20	0·80	0·60	0·25	-0·45	..	..	..	0	0	0	0
1·20	·80	·60	·25	- ·45	6·8	8·2	(?)	..	..	..	..
1·20	·80	·60	·25	- ·50	..	..	..	..	..	..	..
1·20	·80	·65	·25	- ·45	7·4	8·3	(?)	..	..	..	..
1·25	·85	·65	·25	- ·45	..	..	..	1,769	1,769	19,406	19,406
1·30	·80	·65	·25	- ·45	7·6	9·2	0·4	..	..	..	..
1·25	·80	·65	·25	- ·50	..	..	..	..	.	..	..
1·25	·80	·65	·25	- ·50	7	8·6	1·8	..	..	..	..
1·25	·80	·65	·25	- ·50	..	..	..	1,819	3,588	20,023	39,429
1·25	·80	·65	·25	- ·50	7·1	9·3	1·4	..	..	..	..
1·25	·80	·65	·25	- ·50	..	..	..	..	..	..	..
1·25	·80	·65	·25	- ·50	7·1	9	1·3	..	..	..	..
1·25	·80	·65	·25	- ·50	..	..	..	1,776	5,364	19,990	59,419
1·30	·75	·65	·25	- ·45	7·1	8	2	..	..	..	..
1·30	·80	·65	·25	- ·50	..	..	..	..	..	..	..
1·30	·75	·65	·25	- ·50	6·8	7·4	2·6	..	..	..	..
1·30	·75	·65	·25	- ·50	..	..	..	1,777	7,141	20,000	79,419
1·30	·75	·65	·25	- ·50	6·6	8·8	1·3	..	..	..	..
1·30	·75	·65	·25	- ·50	..	..	..	..	..	..	..
1·30	·75	·65	·25	- ·50	6·3	9·8	1·7	..	..	..	..
1·30	·75	·65	·25	- ·50	..	..	..	1,705	8,846	18,823	98,242
1·30	·75	·65	·25	- ·50	6·8	9	1·7	..	..	..	..
1·30	·75	·65	·25	- ·50	..	..	..	..	..	..	..
1·30	·75	·65	·25	- ·50	7	9·6	·8	..	..	..	..
1·30	·75	·65	·25	- ·50	..	..	..	1,738	10,584	19,734	117,976
1·27	·78	·642	·25	- ·488	6·97	8·77	1·5	1,764	..	19,663	..

5 p.m. The floor of the furnace is badly warped from the heat. The floor consists of one layer of fire brick on wrought-iron floor plates on wooden sleepers with dirt rammed between the sleepers. The floor of furnace, back wall of same, and first two baffles are red hot. There are two disk-like accumulations of red-hot carbon on the back wall. The middle and larger one is about 15 inches in diameter.

Next day: The disk of carbon has been removed and examined. Structurally, the carbon is indistinguishable from coke. The shape is that of a crater, 5 inches thick around the edges and 2 inches thick in the centre. The larger crater was opposite the middle burners. A smaller one was opposite the left-hand burners and there was practically none opposite the right-hand burners. Evidently a very slight difference of conditions will cause or prevent their formation.

No. 2.—Test of Oil Fuel in a Hohenstein

[Eight hours' duration with

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.			
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Gases at Base of Stack.	Air from Root Blower.
	lbs.	deg. F	deg. F.	deg. F.		ins.	deg. F.	deg. F.	deg. F.	deg. F.
9 a.m. . .	275	122	404	305	0·983	2·5	72	94	..	90
9.15 a.m. .	275	130	404	306	·984	2·5	..	97	520	91
9.30 a.m. .	275	130	404	306	·984	2·5	..	100	..	92
9.45 a.m. .	275	134	404	307	·985	2·25	..	100	525	94
10 a.m.. .	275	122	404	308	·985	2·5	74	99	..	95
10.15 a.m. .	275	130	404	308	·985	2·5	..	101	525	96
10.30 a.m. .	275	130	404	308	·985	2·5	..	102	..	97
10.45 a.m. .	275	128	404	308	·985	2·5	..	102	508	98
11 a.m.. .	275	140	404	307	·984	2·5	76	103	..	99
11.15 a.m. .	275	125	404	306	·984	2·25	..	102	500	100
11.30 a.m. .	275	130	404	307	·985	2·25	..	103	..	100
11.45 a.m. .	275	124	404	307	·984	2·5	..	104	495	100
12 m. . .	275	138	404	306	·984	2	78	105	..	102
12.15 p.m. .	275	134	404	307	·985	2	..	105	495	102
12.30 p.m. .	275	129	404	306	·984	2·25	..	104	..	102
12.45 p.m. .	275	124	404	304	·983	2	..	106	497	103
1 p.m. . .	275	129	404	307	·984	2·25	80	106	..	103
1.15 p.m. .	275	128	404	307	·985	2	..	108	497	104
1.30 p.m. .	275	130	404	307	·984	2	..	109	..	104
1.45 p.m. .	275	123	404	307	·985	2·5	..	109	495	105
2 p.m. . .	275	122	404	306	·984	2·5	82	110	..	106
2.15 p.m. .	275	130	404	308	·985	2	..	109	497	106
2.30 p.m. .	275	136	404	307	·984	2·13	..	111	..	106
2.45 p.m. .	275	124	404	307	·985	2·13	..	112	497	107
3 p.m. . .	275	132	404	306	·984	2	82	111	..	108
3.15 p.m. .	275	130	404	307	·984	2	..	109	500	108
3.30 p.m. .	275	130	404	307	·985	2·13	..	112	..	108
3.45 p.m. .	275	130	404	307	·984	2·25	..	110	502	108
4 p.m. . .	275	124	404	307	·985	2·25	82	111	..	109
4.15 p.m. .	275	129	404	307	·984	2·5	..	114	500	110
4.30 p.m. .	275	130	404	306	·984	2·25	..	112	..	110
4.45 p.m. .	275	122	404	307	·985	2·5	..	112	505	110
5 p.m. . .	275	122	404	307	·984	2·5	82	114	..	111
Average .	275	128·5	..	..	·984	..	79	106	503·6	102·5

State of weather, bright sun, no clouds.
Barometer at noon, 29·70 ins.
Kind of fuel, Beaumont oil.
Revolutions of Root blower, 100 per minute.
Draught openings into furnace, 124 square inches.

WATER-TUBE MARINE BOILER, June 26, 1902.

natural draught, using air burners.]

Air from Root Blower, Pressure per sq. in.	Draught Pressures in Inches of Water.				Flue Gases.			Oil.		Water.	
	Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	Co$_2$.	O.	CO.	Burned per hour.	Total Weight Burned.	Fed per hour.	Total Weight Fed.
lbs.					%	%	%	lbs.	lbs.	lbs.	lbs.
0·73	-0·15	-0·15	-0·25	··0·35	..	..	..	0	0	0	0
·73	- ·15	- ·15	- ·25	- ·35	6·5	11·5	0·2	..	..	..	..
·73	- ·15	- ·15	- ·25	- ·40	..	..	..	..	..	..	..
·67	- ·15	- ·15	- ·25	- ·35	6·4	11	·6	..	..	..	..
·67	- ·15	- ·15	- ·25	- ·35	..	..	..	786	786	9,503	9,503
·79	- ·15	- ·15	- ·25	- ·35	6·6	10	1·3	..	..	..	..
·79	- ·15	- ·15	- ·25	- ·35	..	..	..	..	..	..	..
·73	- ·15	- ·15	- ·25	- ·35	6·6	10·2	·9	..	..	..	..
·73	- ·15	- ·20	- ·25	- ·35	..	..	..	748	1,534	9,061	18,564
85	- ·15	- ·25	- ·25	- ·35	7·1	9·6	·6	..	..	..	..
·85	- ·15	- ·20	- ·25	- ·40	..	..	..	..	..	..	..
·85	- ·15	- ·20	- ·25	- ·35	7·8	9·6	·5	..	..	..	..
·85	- ·15	- ·20	- ·25	- ·35	..	..	..	759	2,293	9,537	28,101
·79	- ·15	- ·20	- ·25	- ·35	7	10·3	·6	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	7·2	9·3	·9	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	751	3,044	9,895	37,996
·79	- ·15	- ·20	- ·25	- ·35	7·5	9·5	0	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	7·8	9·7	0	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	765	3,809	10,066	48,062
·79	- ·15	- ·20	- ·25	- ·35	7·4	10·6	·3	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	7	11·4	0	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	769	4,578	9,482	57,544
·79	- ·15	- ·20	- ·25	- ·35	7·8	10·2	·1	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	7·5	10·5	·2	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	773	5,351	10,373	67,917
·79	- ·15	- ·20	- ·25	- ·35	7·8	9·9	·2	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	7·8	9·9	·4	..	..	..	..
·79	- ·15	- ·20	- ·25	- ·35	..	..	..	771	6,122	10,083	78,000
·78	- ·15	- ·19	- ·25	- ·35	7·24	10·2	·425	765	..	9,750	..

A Brown quick-reading pyrometer placed on the floor of the furnace with the platinum fully exposed to the direct radiations from the flames, registers 1,600° F. under the middle burners. At a point about 18 inches in front of the burner tip and 6 inches below its centre line the temperature is 1,950° F. The corresponding temperatures for the side burners are about 100° lower. The flames reach for the most part to the middle of the combustion chamber. Only rarely do flames penetrate the tube chamber.

5.10 p.m. The smoke was very uniform throughout the test, and so slight as to be barely visible. There are three irregular patches of carbon deposit, one on each side wall of the furnace and one on the back wall. The largest one, on the right side, is dome-shaped, and fully 4 inches thick in the centre.

No. 3.—Test of Oil Fuel in a Hohenstein Water-

[Endurance test of 116 hours' duration

Date.	Watch.	Maximum and Minimum Values observed during each Watch.									
						Temperature.				Root Blower.	
		Steam Pressure by Gauge.	Temperature of Feed Water.	Quality of Steam.	Height of Water in Gauge Glass.	Outside Air.	Air in Fire Room.	Gases at Base of Stack.	Air from Root Blower.	Revolutions per Minute.	Air Pressure per Square Inch.
		lbs.	deg. F.		ins.	deg. F.	deg. F.	deg. F.	deg. F.		lbs.
Monday, Aug. 4 .	Noon to 4 p.m. .	275 275	127 117	0·986 ·984	3·50 2	93 88	121 110	558 550	122 106	98 85	1·34 85
	4 p.m. to midnight	275 275	119 116	·987 ·986	4 2	88 75	124 110	575 558	126 110	99 97	1·40 1·28
Tuesday, Aug. 5	Midnight to 8 a.m.	275 275	122 117	·986 ·986	3 2	80 70	112 104	575 572	112 104	98 90	1·34 1·22
	8 a.m. to 4 p.m. .	275 275	122 112	·986 ·986	3·25 2·50	88 80	120 108	590 570	122 108	104 92	1·34 1·22
	4 p.m. to midnight	275 275	120 118	·987 ·986	2·75 2	88 80	120 116	590 585	122 118	100 97	1·34 1·34
Wednesday, Aug. 6	Midnight to 8 a.m.	275 255	122 102	·987 ·985	3 2	82 73	116 104	610 585	118 107	104 84	1·40 1·22
	8 a.m. to 4 p.m. .	275 255	120 102	·987 ·985	5 2·50	95 73	125 108	610 565	122 112	104 91	1·34 1·16
	4 p.m. to midnight	275 270	130 112	·987 ·985	3·50 2·50	73 72	112 104	605 565	118 106	104 90	1·40 1·16
Thursday, Aug. 7 .	Midnight to 8 a.m.	270 270	124 118	·987 ·986	3 2	74 69	116 107	598 590	114 110	100 92	1·40 1·22
	8 a.m. to 4 p.m. .	276 270	128 112	·987 ·985	4 2	90 74	116 108	600 585	114 108	100 95	1·40 1·22
	4 p.m. to midnight	275 270	124 110	·985 ·985	4 2	81 74	118 100	595 595	116 108	100 97	1·40 1·34
Friday, Aug. 8 .	Midnight to 8 a.m.	275 265	124 119	·985 ·983	3·75 1·50	74 70	106 98	595 550	108 101	103 92	1·40 1·34
	8 a.m. to 4 p.m. .	274 272	128 114	·985 ·983	3·75 1·50	88 73	119 101	625 565	124 102	95 92	1·40 1·28
	4 p.m. to midnight	274 271	125 116	·983 ·982	2·50 1·75	87 74	121 111	605 585	129 110	102 92	1·40 1·40
Saturday. . .	Midnight to 8 a.m.	275 273	128 120	·982 ·982	3 2	80 74	118 103	590 590	116 105	95 94	1·40 1·34
Average of Hourly Observations.	..	273	119·4	·985	..	79	112	585	113·5	96	1·31

Kind of fuel, Beaumont oil. Draught openings into furnace, 848 square inches.

TUBE MARINE BOILER, August 4 to 9, 1902.
with natural draught, using air burners.]

Maximum and Minimum Values observed during each Watch.					Oil.		Water.		Flue Gases.				Height of Barometer at Mid-Watch.	State of Weather.
Draught Pressure in Inches of Water.														
Furnace.	Combustion Chamber.	Tube Chamber.	Above Tubes, below Drums.	Base of Stack.	Burned per Hour and during Watch.	Total Weight Burned.	Fed per hour and during Watch.	Total Weight Fed.	Time Sample was Drawn.	CO$_2$.	O.	CO.		
					lbs.	lbs.	lbs.	lbs.	P.M.	%	%	%	ins.	
-0·25	-0·20	-0·30	-0·40	-0·40	818	..	9,942	..	1.45	7·4	10·8	0·1	29·99	Clear.
- ·15	- ·20	- ·20	- ·35	- ·40	3,270	3,270	39,769	39,769	2	7·4	10·7	0		
- ·20	- ·20	- ·30	- ·40	- ·45	864	..	10,580	..					29·82	
- ·15	- ·20	- ·25	- ·30	- ·40	6,912	10,182	84,638	124,407						
- ·20	- ·25	- ·33	- ·40	- ·50	826	..	10,183	..	A.M.				30·03	Clear.
- ·13	- ·20	- ·28	- ·33	- ·45	6,608	16,790	81,064	205,471						
- ·18	- ·25	- ·30	- ·38	- ·48	847	..	10,520	..	8.45	7·5	10·3	·1	30·00	
- ·15	- ·20	- ·27	- ·35	- ·40	6,773	23,563	84,156	289,627	9.15	7·6	10·2	0		Cloudy; thunderstorm.
- ·18	- ·25	- ·28	- ·35	- ·46	847	..	10,518	..					29·76	
- ·17	- ·22	- ·25	- ·33	- ·40	6,772	30,335	84,148	373,775						
- ·20	- ·28	- ·30	- ·40	- ·50	872	..	10,657	..					29·87	
- ·15	- ·25	- ·25	- ·33	- ·45	6,974	37,309	85,253	459,028						Rain.
- ·18	- ·28	- ·35	- ·40	- ·50	848	..	10,487	..	9.30	7·8	10·1	0	29·86	Thunderstorm.
- ·13	- ·22	- ·30	- ·35	- ·45	6,780	44,089	83,495	542,523	10	7·8	10	0		
- ·20	- ·28	- ·35	- ·45	- ·50	838	..	10,256	..					29·69	
- ·13	- ·23	- ·28	- ·40	- ·48	6,704	50,793	82,044	624,567						
- ·20	- ·25	- ·35	- ·45	- ·50	837	..	10,251	..					29·89	
- ·18	- ·23	- ·30	- ·40	- ·50	6,694	57,487	82,007	706,574						
- ·18	- ·25	- ·33	- ·43	- ·50	836	..	10,414	..	10.30	7·9	10·8	·3	29·98	Clear and cool.
- ·15	- ·23	- ·30	- ·40	- ·48	6,687	64,174	83,315	789,889	10.45	7·8	10·1	·1		
- ·20	- ·25	- ·33	- ·40	- ·48	820	..	10,140	..					29·77	
- ·15	- ·23	- ·28	- ·35	- ·48	6,559	70,733	81,119	871,008						
- ·20	- ·25	- ·35	- ·45	- ·50	819	..	10,151	..					29·89	
- ·20	- ·23	- ·28	- ·40	- ·48	6,551	77,284	81,204	952,212						
- ·20	- ·25	- ·33	- ·40	- ·50	816	..	10,127	..	9.30	7·8	9·7	0	29·91	Clear; then partly cloudy.
- ·18	- ·20	- ·25	- ·35	- ·45	6,529	83,813	81,013	1,033,225	10	7·8	9·8	0		
- ·19	- ·22	- ·31	- ·40	- ·48	809	..	10,145	..					29·81	
- ·15	- ·20	- ·28	- ·35	- ·41	6,452	90,265	81,163	1,114,388						
- ·18	- ·22	- ·30	- ·40	- ·48	782	..	9,762	..					30·05	Partly cloudy.
- ·15	- ·20	- ·30	- ·35	- ·42	6,252	96,517	78,094	1,192,482	..	..	..	..		
- ·17	- ·23	- ·30	- ·36	- ·46	832	..	10,280	..	Average.	7·68	10·25	·06	29·89	

No. 4.—TEST OF OIL FUEL IN A HOHENSTEIN

[Six hours' duration with natural

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.			
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Oil in Weighing Tank.	Gases at Base of Stack.
	lbs.	deg. F.	deg. F.	deg. F.		ins.	deg. F.	deg. F.	deg. F.	deg. F.
1.30 p.m.	275	122	388	302	0·988	2·5	76	96	..	460
1.45 p.m.	275	120	386	304	·989	2·75	77	95	..	..
2 p.m.	275	119	386	306	·991	2·75	77	98	72·5	440
2.15 p.m.	275	120	386	308	·992	2·5	77	98	..	..
2.30 p.m.	274	134	386	308	·992	2·5	78	98	..	..
2.45 p.m.	275	125	386	308	·992	2·5	79	99	..	..
3 p.m.	275	130	386	308	·992	2·75	79	100	72	..
3.15 p.m.	275	137	386	308	·992	2·75	77	99	..	..
3.30 p.m.	275	140	386	308	·992	2·5	78	98	..	..
3.45 p.m.	275	138	386	308	·992	2·75	77	99	..	..
4 p.m.	275	137	386	303	·989	2·75	77	99	72	..
4.15 p.m.	275	130	386	303	·989	3	77	100	..	..
4.30 p.m.	275	136	386	303	·989	2·5	78	100	..	..
4.45 p.m.	276	124	386	306	·991	2·5	76	99	..	450
5 p.m.	275	118	384	306	·991	2·5	74	100	72	..
5.15 p.m.	275	130	386	308	·992	2·75	74	99	..	445
5.30 p.m.	275	120	386	308	·992	2·5	74	99	..	..
5.45 p.m.	275	130	386	306	·991	2·5	74	98	..	..
6 p.m.	275	130	386	306	·991	2·5	73	99	72	..
6.15 p.m.	275	130	384	306	·991	2·5	72	98	..	..
6.30 p.m.	275	120	384	306	·991	2·5	70	97	..	..
6.45 p.m.	275	122	384	306	·991	2·5	70	96	..	..
7 p.m.	275	122	384	306	·391	2·5	70	94	71	..
7.15 p.m.	275	124	384	306	·991	2·5	70	94	..	..
7.30 p.m.	275	120	386	306	·991	2·5	68	92	..	..
Average	275	127	..	..	·991	..	75	98	72	449

State of weather, partly cloudy.
Barometer at noon, 30·16 inches.
Kind of fuel, Beaumont oil.
Draught opening into furnace, 180 square inches.
Pressure in oil-pipe air chamber, 20·3 lbs.
Temperature over fire-room platform, average 165° F., maximum 170° F.

WATER-TUBE MARINE BOILER, September 12, 1902.

draught, using "Hayes" steam burners].

Pressure of Steam used in Spraying Oil.	Draught pressures in Inches of Water.				Flue Gases.			Oil burned.		Steam used by Burners.		Feed Water.	
	Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	CO₂.	O.	CO.	Per hour.	Total.	Per hour.	Total.	Per hour.	Total.
lbs. 30	-0·20	-0·20	-0·20	-0·32	% 5·6	% 12·7	% 0·2	lbs. 0	lbs. 0	lbs. 0	lbs. 0	lbs. 0	lbs. 0
30	-. 20	- ·20	- ·20	- ·38	..	..	..	..	..	..	..	..	..
32	- ·18	- ·20	- ·20	- ·35	4·8	13·7	·3	..	..	..	..	..	..
32	- ·19	- ·20	- ·22	- ·33	..	..	..	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·32	..	..	..	572	572	456	456	6,702	6,702
33	- ·18	- ·20	- ·22	- ·38	..	..	..	..	..	..	..	..	..
33	- ·21	- ·20	- ·20	- ·38	..	..	..	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·38	..	..	..	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·38	..	..	..	601	1,173	402	858	7,311	14,013
32	- ·20	- ·20	- ·20	- ·35	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·20	- ·35	..	..	..	..	..	..	..	..	..
31	- ·20	- ·20	- ·20	- ·35	..	..	..	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·38	..	..	..	602	1,775	553	1,311	7,241	21,254
32	- ·20	- ·20	- ·20	- ·40	6	12·8	·3	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·38	..	..	..	..	..	..	..	..	..
32	- ·20	- ·20	- ·20	- ·38	5·6	13	·3	..	..	..	..	..	..
32	- ·21	- ·21	- ·21	- ·40	..	..	..	590	2,365	459	1,770	7,480	28,734
32	- ·22	- ·21	- ·21	- ·40	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·40	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·40	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·40	..	..	..	639	3,004	295	2,065	7,691	36,425
32	- ·22	- ·21	- ·21	- ·41	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·41	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·41	..	..	..	..	..	..	..	..	..
32	- ·22	- ·21	- ·21	- ·41	..	..	..	596	3,600	459	2,524	7,836	43,761
32	- ·205	- ·204	- ·205	- ·38	5·5	13·05	·27	600	..	421	..	7,294	..

10.30 a.m. Started fires. The boilers were under steam yesterday and the water is already quite warm.

12.30 to 1.30 p.m. Data taken during this period shows about the same evaporative capacity as during the succeeding six hours. The smoke ranged from ½ to 1. Average, ¾, by Ringlemann charts. A few ounces of carbon was deposited near the right-hand burner orifice. The burners made comparatively little noise, probably not more than a quarter as much as the compressed-air burners used in the preceding eight tests; but on the other hand, the flames were longer, reaching well into the tube chamber.

No. 5.—Test of Oil Fuel in a Hohenstein Water-

[Eight hours' duration with natural

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.			
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Oil in Weighing Tank.	Gases at Base of Stack.
	lbs.	deg. F.	deg. F.	deg. F.		ins.	deg. F.	deg. F.	deg. F.	deg. F.
10.30 a.m.	275	118	380	308	0·994	2·75	62	90	..	..
10.45 a.m.	275	120	380	308	·994	2·75	63	91	..	600
11 a.m.	275	118	380	308	·994	2·75	64	90	68	..
11.15 a.m.	275	118	380	308	·994	2·50	64	90	..	..
11.30 a.m.	275	115	380	308	·994	2·50	66	91	..	..
11.45 a.m.	275	118	380	309	·995	2·50	66	92	..	605
12 m.	275	116	380	310	·995	2·50	67	99	68	..
12.15 p.m.	275	115	380	310	·995	3	67	99	..	..
12.30 p.m.	275	118	382	310	·995	2·50	68	100	..	..
12.45 p.m.	275	110	380	310	·995	2·50	68	101	..	600
1 p.m.	275	112	380	310	·995	2·50	69	100	68	..
1.15 p.m.	275	118	380	310	·995	2·50	70	100	..	..
1.30 p.m.	275	120	380	310	·995	2·50	71	100	..	..
1.45 p.m.	275	120	384	310	·994	3	71	95	..	605
2 p.m.	275	120	384	310	·994	3	71	98	68	..
2.15 p.m.	275	118	384	310	·994	3	70	98	..	..
2.30 p.m.	270	118	384	310	·994	2·50	70	96	..	..
2.45 p.m.	275	118	384	310	·994	2·50	70	96	..	580
3 p.m.	275	120	384	310	·994	2·50	70	94	68	..
3.15 p.m.	275	122	384	310	·994	2·50	71	100	..	..
3.30 p.m.	275	120	384	310	·994	2·50	71	100	..	..
3.45 p.m.	275	120	384	310	·994	2·50	70	98	..	575
4 p.m.	275	122	384	310	·994	3	70	94	68	..
4.15 p.m.	275	118	384	310	·994	2·50	70	98	..	..
4.30 p.m.	274	118	384	310	·994	2·50	70	102	..	..
4.45 p.m.	274	118	380	310	·995	2·50	70	110	..	595
5 p.m.	275	118	380	310	·995	2·50	70	106	68	..
5.15 p.m.	275	120	380	310	·995	2·50	70	104	..	..
5.30 p.m.	274	120	380	310	·995	2·50	70	104	..	..
5.45 p.m.	274	120	380	310	·995	2·50	70	100	..	610
6 p.m.	274	120	380	310	·995	2·50	70	100	69	..
6.15 p.m.	274	118	380	310	·995	2·50	70	104	..	..
6.30 p.m.	275	120	360	308	1·001	2·75	70	99	..	..
Average	274·6	118·3	..	..	·995	..	69	98	68·1	596

State of weather, thin clouds.
Barometer at noon, 30·20 inches.
Kind of fuel, Beaumont oil.
Draught opening into furnace, 500 square inches.
Pressure in oil-pipe air chamber, 20 pounds.
Temperature over fire-room platform, average 177° F., maximum 184° F.
Temperature of superheated steam for burners, 444·4° F.

TUBE MARINE BOILER, September 19, 1902.

draught, using steam burners.]

Pressure of Steam used in Spraying Oil.	Draught Pressures in Inches of Water.				Flue Gases.			Oil burned.		Steam used by Burners.		Feed Water.	
	Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	CO_2.	O.	CO.	Per hour.	Total.	Per hour.	Total.	Per hour.	Total.
lbs.					%	%	%	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
28	-0·20	-0·15	-0·20	-0·60	..	..	..	0	0	0	0	0	0
29	- ·18	- ·18	- ·20	- ·60	7	10·6	0	..	..	..	..	..	..
30	- ·20	- ·20	- ·20	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	983	983	475	475	11,181	11,181
29	- ·20	- ·20	- ·30	- ·60	7·1	11·1	0	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
31	- ·20	- ·20	- ·30	- ·60	..	..	..	968	1,951	365	840	11,143	22,324
30	- ·20	- ·20	- ·30	- ·60	7	11·2	·1	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	934	2,885	423	1,263	11,222	33,546
30	- ·20	- ·20	- ·30	- ·60	7	11·1	0	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·_0	- ·20	- ·30	- ·60	..	..	..	915	3,800	326	1,589	10,551	44,097
28	- ·20	- ·20	- ·30	- ·60	6·6	11·2	0	..	..	..	..	..	..
28	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
28	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
28	- ·20	- ·20	- ·30	- ·60	..	..	..	851	4,651	399	1,988	10,287	54,384
28	- ·20	- ·20	- ·30	- ·60	6·6	11·8	0	..	..	..	..	..	..
28	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·60	..	..	..	..	..	..	..	..	..
30	- ·20	- ·20	- ·30	- ·55	..	..	..	826	5,477	479	2,467	9,733	64,117
32	- ·22	- ·22	- ·25	- ·60	7·4	10·8	0	..	..	..	..	..	..
32	- ·22	- ·22	- ·25	- ·60	..	..	..	..	..	..	..	..	..
32	- ·22	- ·22	- ·25	- ·60	..	..	..	..	..	..	..	..	..
32	- ·22	- ·22	- ·25	- ·60	..	..	..	970	6,447	452	2,919	11,071	75,188
32	- ·21	- ·21	- ·25	- ·58	7·2	10·6	0	..	..	..	..	..	..
32	- 21	- ·20	- ·25	- ·58	..	..	..	..	..	..	..	..	..
31	- ·20	- ·20	- ·28	- ·58	..	..	..	..	..	..	..	..	..
29	- ·20	- ·20	- ·28	- ·58	..	..	..	913	7,360	493	3,412	10,603	85,791
29·9	- ·202	- ·201	- ·281	- ·596	6·99	11·05	·013	920	..	427	..	10,724	..

The angular setting of the side burners is changed so as to direct their flames more toward the centre of the furnace. Heretofore the side walls of the furnace have absorbed an undue amount of heat, as shown by their glow after extinguishing the burners.

Curved sheet-iron deflectors have been placed in what were formerly the ash pit openings, so as to direct the entering air upward at an angle against the flames.

The smoke averages about ¼, the maximum being ⅓, by Ringelmann charts.

A disk of carbon 9 inches in diameter was deposited on the back wall opposite the centre burners.

The burners make much less noise than those made by the same builders using air.

PRODUCTION OF PETROLEUM IN THE CHIEF OIL PRODUCING COUNTRIES.

United States. (In Thousands of Barrels.)

Years.	Pennsylvania and New York.	Ohio.	West Virginia.	California.	Indiana.	Texas.	Total including other Fields.
1860	500	...	...	...	...	...	500
1870	5,261	...	...	...	...	...	5,261
1875	8,788	...	...	...	...	...	12,163
1880	26,028	39	179	41	...	...	26,286
1885	20,776	662	91	325	...	...	21,859
1886	25,798	1,783	102	377	...	...	28,064
1887	22,356	5,023	145	679	...	...	28,283
1888	16,480	10,010	119	690	...	...	27,612
1889	21,487	12,471	544	303	33	...	35,164
1890	28,458	16,125	493	307	63	...	45,824
1891	33,009	17,740	2,406	324	137	...	54,293
1892	28,422	16,363	3,810	385	698	...	50,510
1893	20,315	16,250	8,445	470	2,335	...	48,431
1894	19,020	16,792	8,578	706	3,689	...	49,345
1895	19,144	12,545	8,120	1,208	4,386	...	52,892
1896	20,584	23,941	10,020	1,253	4,681	1	60,960
1897	19,262	21,561	13,090	1,903	4,122	66	60,476
1898	15,948	18,739	13,651	2,257	3,731	546	55,364
1899	14,375	21,142	13,911	2,642	3,848	669	57,071
1900	14,559	22,363	16,195	4,099	4,874	836	63,362
1901	...	...	...	...	...	...	69,389
1902	...	...	...	...	...	...	84,250

Russia.

Year.	Total Production. Poods.*	Number of Producing Wells.	Average per Well for Year. Poods.
1894	297,551,021	532	559,306
1895	377,426,620	604	624,879
1896	386,264,782	735	525,530
1897	422,658,213	904	467,542
1898	485,943,348	1,107	438,973
1899	525,247,415	1,357	387,065
1900	600,763,812	1,710	351,323
1901	608,500,000	1,924	316,270
1902	582,700,000	2,039	285,777
1903	597,000,000	1,877	318,060

* In round figures 62 poods = 1 ton.

India—Burma and Assam.
(Thousand Gallons.)

1890	4,132	1897	19,099
1891	6,554·5	1898	18,973·8
1892	8,470·9	1899	32,934
1893	10,463·9	1900	37,729·2
1894	11,452·6	1901	50,000
1895	13,000·3	1902	56,556
1896	15,044·5		

Other Countries, 1903.
(Thousand Barrels.)

Dutch Indies, .	5,860
Galicia, . .	4,142
Roumania, .	2,480
Japan, . .	1,190
Canada, . .	520
Alsace, . .	625

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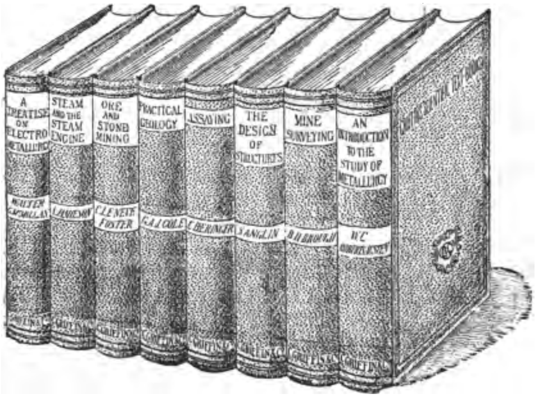

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